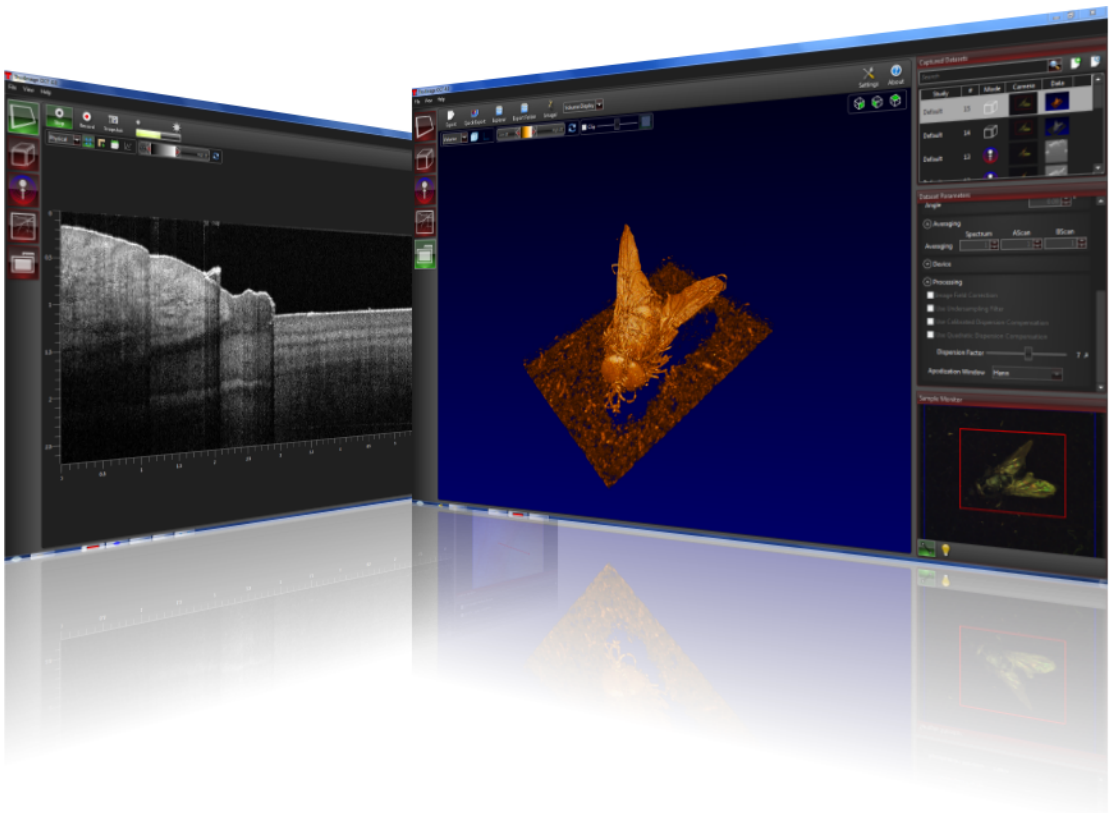
Optical Coherence Tomography

ThorImage®OCT

User Guide



Version 5.8

Revision: C
Date: January 27, 2025

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Chapter 1 Introduction

1.1 Intended Use

The ThorImage®OCT is designed for general laboratory use. Integrated routines allow advanced imaging (including acquisition, processing, and visualization), and data management (import/export).

The ThorImage®OCT may only be used in accordance with the instructions described in this user guide. Any other use will invalidate the warranty.

1.2 Explanation of Safety Warnings

NOTICE Indicates information considered important, but not hazard-related, such as possible damage to the product.

CE
UK CA

The CE/UKCA markings on the product are the manufacturer's declaration that the product complies with the essential requirements of the relevant European health, safety, and environmental protection legislation.

1.3 Description

The ThorImage®OCT is an advanced imaging and data management application that works with Thorlabs optical coherence tomography (OCT) imaging systems and provides a comprehensive user interface for the acquisition, display, and management of OCT data. This 64-bit Windows® based software acquires and displays OCT data, as well as includes scan control and processing options. The ThorImage®OCT offers a high degree of flexibility by enabling easy point-and-click scan pattern creation and being able to edit scanning parameters directly. Visual enhancements of the OCT image view can be achieved by adjusting contrast and brightness, choosing among different colormaps and views or switching between sectional view, surface view, or volume rendering in 3D acquisition.

OCT files are saved in an extensible proprietary file format, and the state in which the OCT data is saved in the file can be specified. The processed data format covers most requirements, while the storage of raw spectral data is intended for advanced scientific users who want to use their own processing algorithms.

The ThorImage®OCT provides 1D, 2D, and 3D OCT data acquisition and processing. Acquired OCT data can be saved, opened, and viewed in all standard image formats. In addition, OCT data can be exported and converted into the formats listed in the following table:

Standard Image Formats	Extended Image Formats
PNG	FITS
JPEG	VTK
BMP	VFF
PDF	TXT
TIFF[a]	CSV
AVI	RAW[b]

a. 32-Bit Only

b. Binary Raw Processed Data Only

Table 1 Image File Formats

Further information on the image formats can be found in the Data Formats and Image Formats sections.

ThorImage® OCT makes it possible to:

- Import Legacy Data Files Acquired with Thorlabs SD-OCT Software
- Export Legacy Data Files Acquired Thorlabs SD-OCT Software

These files should have the extensions .RAW or .SDR.

The binary raw processed data is supported by open-source image processing software such as ImageJ, ParaView, or MicroView. Advanced processing techniques such as optical coherence angiography (Speckle Variance Contrast Imaging) and Doppler OCT complete the application's main feature set. The ThorImage®OCT offers a high degree of flexibility through the easy creation of scan patterns and the ability to edit scan parameters directly.

Additionally, LabVIEW™, Python, MATLAB®, and C based software development kits (SDKs) are available, which contain a complete set of libraries for measurement control, data acquisition, and processing, as well as for storage and display of OCT images. The SDKs provide the means for developing highly specialized OCT imaging software for every individual application.

The following points characterize the ThorImage®OCT:

- Interactive Scan Position Control through Video Display for Common Line Scans or Freeform Pattern Scans
- Versatile Scan and Acquisition Control, such as Averaging or Adjustable Scan Speeds
- Advanced Dataset Management
- Access to Raw Spectra Data, Processsed Data, and All Calibration Files Necessary for User-Designed Processing Routines
- High-Speed Volume Rendering of 3D Data
- Doppler and Speckle Variance Imaging
- Python Processing

1.4 Compatible Devices

Series	Model
GANYMEDE SD-OCT	
	GAN111
	GAN312 & GAN612
	GAN332 & GAN362
TELESTO SD-OCT	
	TEL221 & TEL321
	TEL411 & TEL511
TELESTO Polarization-Sensitive SD-OCT	
	TEL211PS & TEL221PS
ATRIA SS-OCT (ATR200)	
	ATR206 & ATR220
VEGA SS-OCT (VEG200)	
	VEG210 & VEG220

Table 2 Compatible Devices for the ThorImage®OCT

If there are any questions about the compatibility of the ThorImage®OCT with older devices, please contact the Thorlabs OCT Support.

Chapter 2 Installation

2.1 Warranty and RMA Information

Thorlabs warrants material and production of the ThorImage®OCT for a period of 24 months starting with the date of shipment in accordance with and subject to the terms and conditions set forth in Thorlabs' General Terms and Conditions of Sale which can be found at:

General Terms and Conditions:

https://www.thorlabs.com/Images/PDF/LG-PO-001_Thorlabs_terms_and_%20agreements.pdf

and

https://www.thorlabs.com/images/PDF/Terms%20and%20Conditions%20of%20Sales_Thorlabs-GmbH_English.pdf

2.2 Requirements

2.2.1 Hardware

Note that the ThorImage®OCT uses an Intel compiler and is therefore optimized for Intel CPUs.

Spectral Domain Systems CAL, GAN, TEL

- **CPU** Minimum: 3.6 GHz, 4 Core Intel CPU
  Recommended: 3.0 GHz, 8 Core Intel CPU
- **RAM** Minimum: 8 GB Internal Memory
  Recommended: 32 GB Internal Memory
- **Graphic Card** Minimum: AMD FirePro W2100 2GB, or comparable by NVIDIA
  Recommended: AMD Radeon Pro WX 3100 4GB,
  NVIDIA Quadro P1000 4 GB[a]
- **Hard Drive** 512 GB SSD/HDD (≥20 GB Free Hard Drive Capacity)
- **Interface** Free USB 3.0 Port

Camera Framegrabber Card

The system includes a Framegrabber Card, with the exact type depending on the specific system configuration.

- **Current System Generation**[b]
  Matrox Dual CameraLink Framegrabber Card or CoaXPress Framegrabber Card
- **Previous System Generations**[c]
  National Instruments PCIe CameraLink

This is only required if the computer should be used for OCT data acquisition together with the CameraLink-based Thorlabs OCT unit.

a. The difference between VEG and ATR is that the ATR collects significantly more data points per measurement. Therefore, the RAM and graphics card need to be more powerful.

b. Systems that were manufactured after September 2020, i.e. GANxx1, GANxx2, and TELxx1 Series, as well as GAN6x0 Series.

c. Systems that were manufactured in or before September 2020, i.e. GAN2x0, Ganymede(-II/III), TELxx0, Telesto(-I/II) Series.

Swept-Source Systems VEG & ATR

- **CPU** Minimum:4 Cores, 3.6 GHz Intel CPU
  Recommended: 8 Cores, 3.0 GHz Intel CPU
- **RAM** Minimum: 8 GB Internal Memory
  Recommended: 32 GB, 64 GB Internal Memory for ATR206
- **Graphic Card** Recommended: AMD Radeon Pro WX3100
  or NVIDIA Quadro P1000 4GB, ATR206 NVIDIA Only
- **Interface** Free USB 3.0 Port

Note that, ATR206 systems record more data points. An NVIDIA graphics card is therefore used for rendering. AMD graphics cards are not designed for this.

2.2.2 Software

The ThorImage®OCT is compatible with the following operating systems:

- Windows® 10 (64-bit, Compatibility for ThorImage®OCT Version 4.4.8 or Higher)
- Windows® 11 (Compatibility for ThorImage®OCT Version 5.7 or Higher)

If errors occur during the installation of NI (e.g. C++ runtime errors that prevent the installation), please refer to the following notes on the website.

2.3 Installation Instructions

Prior to starting the installation, make sure that administrator rights are enabled. If there are no administrator rights, please contact the system administrator.

NOTICE

NOTICE: Clean Installation!

- Do not connect the OCT Imaging System to the PC prior to ThorImage®OCT installation.
- Exit all running applications on the PC as the installer may require a reboot of the PC during installation.

General

1. Connect the USB thumb drive shipped with the OCT Imaging System.
2. Run the installer executable *OCT_{Version}.exe* from the thumb drive by right-clicking the *Executable* and selecting *Run as administrator*.
3. Choose the right OCT Imaging System type when setting up a data acquisition workstation or select "Offline Data Viewing", if the software is used for data viewing and/or exporting purposes only.

   ➤ If an update is performed and an older ThorImage®OCT version is already installed, the installer checks and selects the required data packages automatically.

   ➤ If there is an existing system with configuration files, those can be transfered to an new PC by copying the folder C:\Program Files\Thorlabs\SpectralRadar\config from the original OCT Imaging System PC to the same location on the new PC. With this the Configuration Settings are copied to the new PC and the OCT Imaging System can be operated easily.

Telesto & Ganymede Users

Please keep in mind that National Instruments' licensing connects the framegrabber card to the NI Vision Acquisition software required to drive the framegrabber. NI Vision Acquisition may only be installed on the PC containing the framegrabber card.

Should any problems arise with the installation or any questions and/or feedback regarding the software, please contact the Thorlabs OCT Support.

Python

A valid installation of Python version 3.11 must be accessible through the system path variable. The following packages should be installed globally. There is need for administrator permission before installing the packages via "pip install".

- numpy == 1.26.4
- matplotlib == 3.9.2
- scipy == 1.14.1

To ensure a compatible Python installation, please follow these installation instructions:

1. Download the latest version of Python version 3.11 from the website.
2. Install the Python software.
   ➤ Make sure the path is added to the custom system path variable either through the installer or manually.
3. Open a command window with admin privileges and navigate to the python installation folder.
4. Run pip to download and install the required packages.
   ➤ Pip install numpy == 1.26.4 matplotlib == 3.9.2 scipy == 1.14.1

Chapter 3 Graphical User Interface (GUI)

This chapter provides an overview of the ThorImage®OCT Graphical User Interface (GUI) and its main controls. The GUI is divided into several regions offering different options, actions, and properties.

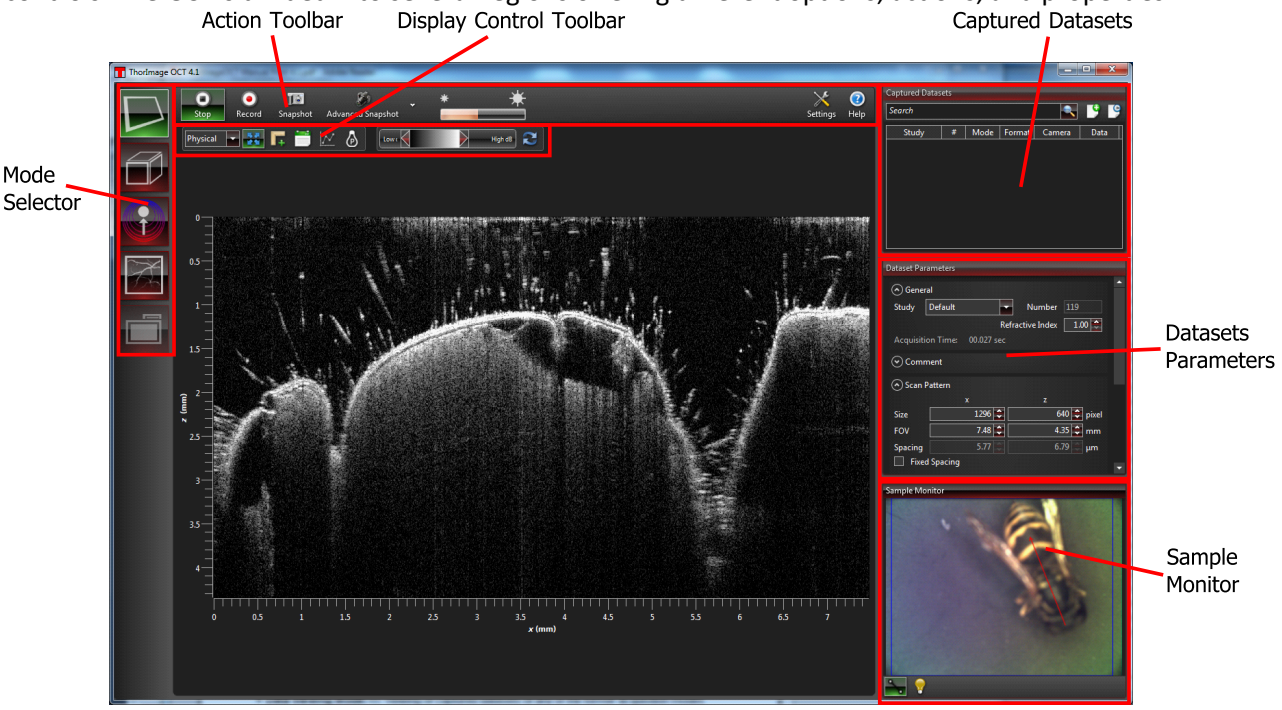


Figure 1 Overview of the Graphical User Interface (GUI)

Mode Selector Bar

Use the Mode Selector Bar to switch between the ThorImage®OCT's acquisition modes:

- 1D Acquisition: Acquisition of 1D Data (A-Scans)
- 2D Acquisition: Acquisition of 2D Data (B-Scans)
- 3D Acquisition: Acquisition of Volume Scans
- Doppler Acquisition Mode: Acquisition of Doppler OCT Data
- Speckle Variance Contrast Mode: Acquisition of Speckle Variance Data
- 2D Polarization-Sensitve Mode: Acquisition of 2D Polarization-Sensitive OCT Data
- 3D Polarization-Sensitive Mode: Acquisition of 3D Polarization-Sensitive OCT Data
- Python 1D Acquisition: Acquisition of 1D Data Processed with External Python Script
- Python 3D Acquisition: Acquisition of 3D Data Processed with External Python Script
- Data Viewing Mode: Viewing of Captured Datasets of Any of the Former Acquisition Modes

Menu Bar

The Menu Bar is invisible by default. The visibility of the menu bar can be toggled either by using the *Alt* key or the *F10* key or by changing the corresponding setting in the settings dialog.

Hiding and showing the Menu Bar can be toggled by the *Alt* or *F10* keys.

Figure 2 Menu Bar (Hiding and Showing the Menu Bar)

Action Toolbar

The Action Toolbar controls actions in the current acquisition mode. Start and stop data acquisition with the *Scan/Stop* button. Capture single snapshots or entire scans with the *Record* button. The bar with two sun symbols shows the current reference intensity, if applicable to your OCT Imaging System.

When viewing datasets, the Action Toolbar shows options for opening the dataset in ImageJ (if installed) or exporting the data to various formats.

Display Toolbar

The Display Control Toolbar adjusts the display of live or offline OCT data using the available controls. These include setting color modes, selecting aspect ratios, performing distance measurements, or showing a single A-Scan in a B-Scan.

Captured Datasets

The Captured Datasets list displays all datasets acquired during a ThorImage® OCT session. For each dataset the list shows the acquisition mode in which it was acquired along with a preview picture of both the sample monitor and the OCT data, as well as the study name, the experiment number and the storage format. Left-clicking a list entry will activate and display the selected dataset.

Dataset Parameters

When acquiring data, this panel contains the parameters used in the currently running acquisition. In data viewing mode, the parameters used to acquire the currently active dataset are displayed. These include their identifier (study name and experiment number), the refractive index of the data, user-defined comments for the current dataset, acquisition parameters (like B-Scan size, volume size, scan orientation, etc.), and processing and averaging parameters that influence imaging quality.

Sample Monitor

The Sample Monitor shows the live video image from the probe camera. A blue boundary indicates the maximum scan range. The current scan line or area is drawn in red and can be set with the mouse using the draw & scan feature. When viewing a captured dataset, it usually contains a still image from the probe's camera at the time of acquisition.

The contents of the Action Toolbar, Display Control Toolbar, and Dataset Parameters control depend on the active acquisition mode and are explained in the corresponding sections of this user guide.

3.1 Viewing Options

All controls, except for the OCT display in the center and the mode switching buttons on the extreme left, are arranged in Tool Windows. Tool windows can be undocked and rearranged within and outside of the application window by clicking on the Tool Window title bar and dragging it to a different location. A Tool Window can remain undocked in a floating position or docked to different target areas. To dock a Tool Window to a different location in the application screen, drag the window until it hovers over a highlighted target area. Then, release the window for it to dock at that new location. Additionally, tool windows can be automatically hidden or arranged in tabbed interfaces. For the former, click on the down arrow in the upper right corner of a Tool Window and select *Auto Hide*. For the latter, drag the Tool Window on top of another Tool Window. The two Tool Windows will then share a common tab interface.

The window configuration will be restored when closing and restarting the application.

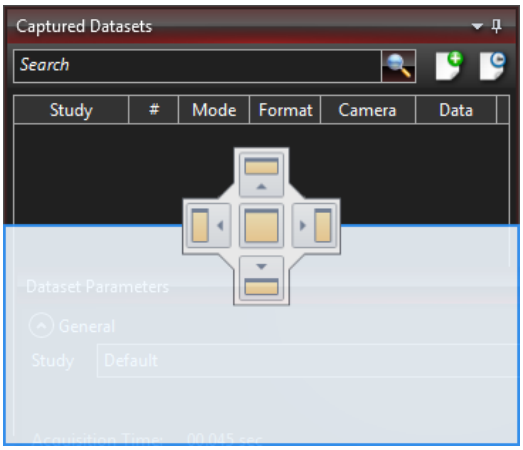


Figure 3 Drop Markers and Highlighted Target Area During a Tool Window Dragging Operation

Two different Default Windows layout configurations can be loaded by choosing the respective entries from the View Menu:

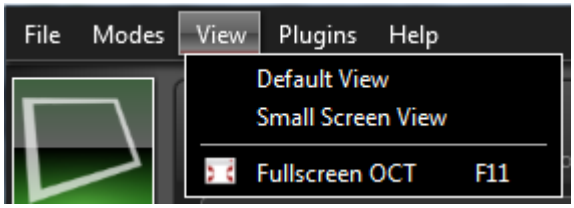


Figure 4 Viewing Options in the View Menu

- **Default View**
  The default configuration for wide screen displays. The Captured Datasets, Dataset Parameters, and Sample Monitor controls are located on the right.
- **Small Screen View**
  This configuration is for small screens with a 4:3 aspect ratio. The Captured Datasets, Dataset Parameters, and Sample Monitor controls are located at the bottom.

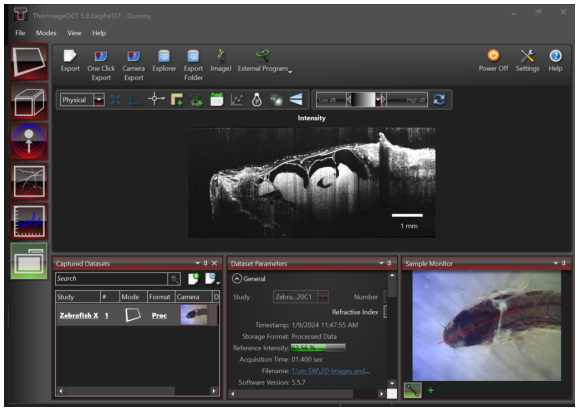


Figure 5 (Left) Default View Configuration
Figure 6 (Right) Small Screen View Configuration

Fullscreen Mode

The Fullscreen Mode can be toggled by either pressing *F11* or by using the fullscreen OCT entry in the view menu. Activating Fullscreen Mode also removes the window decorations (the application's window title bar and icons) and the task bar.

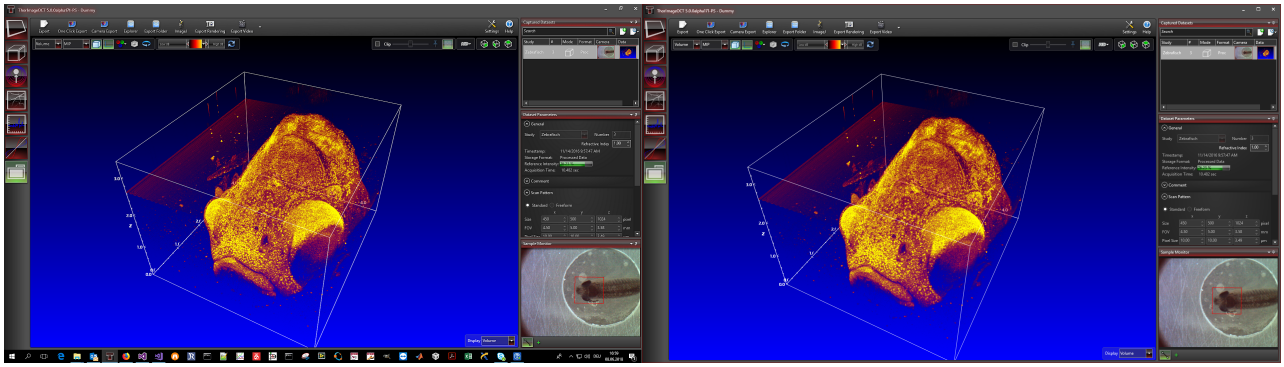


Figure 7 (Left) Application in Regular Appearance (Title Bar and Window Decorations On)
Figure 8 (Right) Application in Fullscreen Mode (Title Bar and Window Decorations Off)

3.1.1 Data Viewing Mode

The ThorImage®OCT starts in data viewing mode if no OCT device is connected and powered on. A warning will appear indicating that the OCT device could not be initialized. This warning can be ignored if data acquisition is not needed. All data acquisition modes will be disabled in this mode.

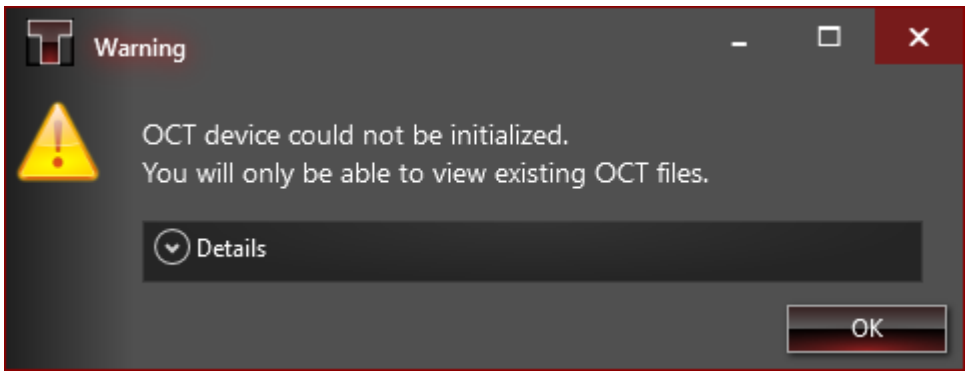


Figure 9 Screenshot of Warning Indicating "The Device Could Not Be Found"

In the data viewing mode, data files can be opened using the *Open Dataset* or, if available, the *Recent Datasets* button in the captured datasets tool window. The datasets will be added to the dataset list and can be handled in the same way as if the device was connected.

The following screenshot shows the ThorImage®OCT when started in data viewing mode. The *Open Dataset* and *Recent Datasets* buttons in the upper right corner are highlighted in red.

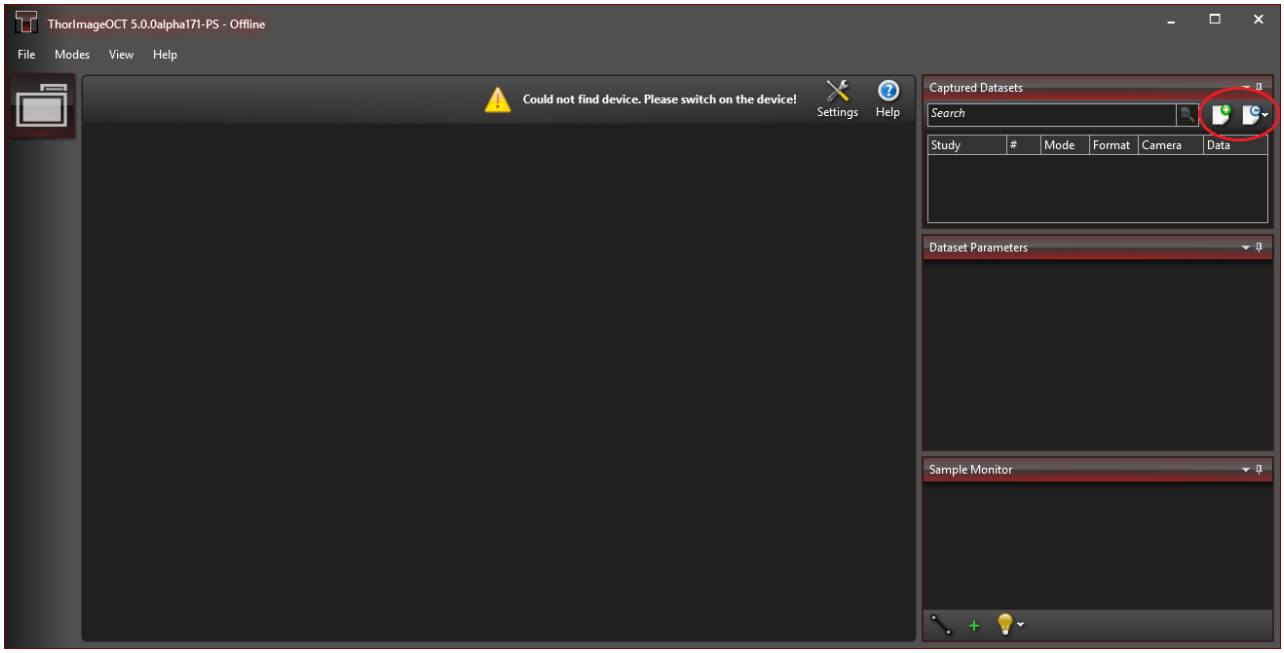
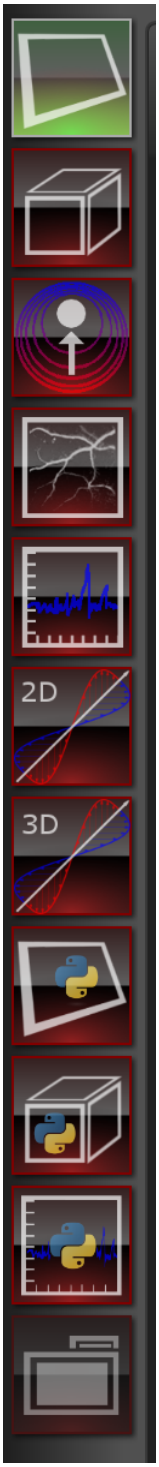


Figure 10 ThorImage®OCT Started in Data Viewing Mode

As long as no data set is loaded, the dataset parameters, sample monitor, and toolbar will not be shown.

3.2 Mode Selector Bar

OCT imaging can be performed in different modes selected using the mode selector bar. If a Thorlabs OCT device is connected and on, the first five modes will be available. If no OCT device is present, only the data viewing mode for viewing and exporting OCT data will be available.



- 1D Acquisition
- 2D Acquisition
- 3D Acquisition
- Doppler Acquisition Mode
- Speckle Variance Contrast Mode
- 2D Polarization-Sensitve Mode[a]
- 3D Polarization-Sensitive Mode[a]
- Python 1D Acquisition[b]
- Python 3D Acquisition[b]
- Data Viewing Mode

Figure 11 Mode Selector Bar

a. These operating modes are only available if the system hardware enables polarization-dependent measurements.
b. These operating modes are only displayed if the corresponding settings option is enabled by the user.

3.2.1 OCT Modes

To obtain the depth information (A-Scan) from a spectrum acquired by the camera, several processing steps are necessary. The main steps are as follows:

- **Remove Offset Errors**
  Removes offset errors from the camera by subtracting the Offset.data from all spectra (including all apodization spectra).
- **Background Subtraction**
  Removes the DC spectrum by subtracting the mean of all apodization spectra (in general 25 apodization spectra are acquired during each measurement).
- **Apodization**
  Creates the apodization vector by dividing an apodization window function, e.g., a Hann window, by the mean of all apodization spectra. The used apodization window function can be seen in the Processing parameters. The selected apodization window function is displayed in the Processing Parameters. The apodization vector is then applied to all spectra through multiplication.
- **Re-Sampling**
  Interpolation of all data to obtain spectra that are linearly sampled in k-space. The original positions, i.e., positions in λ-space, are given by the Chirp.data.
- **Image Formation**
  Fast Fourier-Transforming (FFT) the spectra and taking the absolute value of the complex data gives the A-Scan. The data are generally stored in dB, which are computed by taking the logarithm to the base 10 and multiplying the data by 20.
- **Display**
  Color mapping is applied to the dB-values.

The above described steps do not specify the algorithm in detail, since the processing chain depends on the chosen settings in the ThorImage®OCT.

Please see the section File Format for how to handle the data, e.g. spectral data from the camera or saved offset errors.

3.2.1.1 1D Acquisition

In 1D Acquisition, the probe beam is positioned statically in space while reflectivity profiles (A-Scans) are collected in the depth direction at the beam position. As an alternative to using the scan parameters window, the beam position can be defined by using the draw & scan feature.

3.2.1.1.1 Action Toolbar

In 1D acquisition, the Action Toolbar looks like the screenshot below.

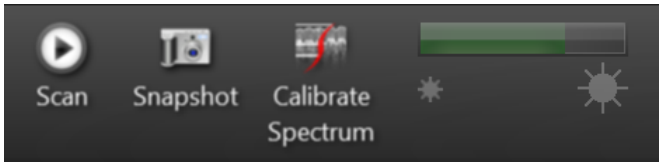


Figure 12 Action Toolbar Options in 1D Acquisition

Preview
Using the *Preview* button starts and stops 1D OCT data acquisition.

Snapshot
When the OCT Imaging System is acquiring 2D data, a single image can be stored using the *Snapshot* button. The acquired M-scan appears in the dataset list and can be selected in order to view it.

Note that raw data storage is not supported in 1D snapshots. When the spectral raw data storage format is selected, a 1D snapshot will yield processed data.

Calibrate Spectrum
Spectral domain systems require a calibration spectrum, which can be captured by pressing the *Calibrate Spectrum* button. To achieve correct results, remove the sample, ensure no signal remains in the OCT image, and click the *Calibrate Spectrum* button in the Action Toolbar.

Note that the *Calibrate Spectrum* button is not available for Swept Source OCT engines, as it is not required in these systems.

3.2.1.1.2 Scan Pattern

In 1D aquisition, set the Scan Pattern by specifying its parameters or using the draw & scan feature. Find the Scan Pattern parameters in the dataset parameters window.

Figure 13 Scan Pattern Window

Draw & Scan
Use the Draw & Scan feature to specify the beam location by clicking on the *video image*. A red cross marks the A-Scan position. The blue rectangle indicates the maximum scan range, so positioning outside these bounds is not possible

Center
Specify the physical coordinate of the A-Scan position using the x and y coordinates relative to the center of the scan area.

Number of Scans
The Number of Scans is the number of the captured A-Scans, which are stored in a ring buffer. A ring buffer works in such a way that it always contains the most recently captured A-Scans.

Repetition Time
The Repetition Time is the time between two consecutive A-Scan measurements. If the averaging parameter is increased, the repetition time increases at the same time.

3.2.1.1.3 Averaging

In 1D acquisition there are two averaging options:

- Spectrum Averaging
- A-Scan Averaging

While Spectrum Averaging is faster, A-Scan Averaging mitigates phase washout that can occur when moving the sample. Both averaging parameters can be combined; their product is however limited to 1000.

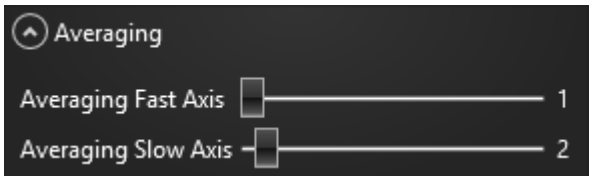


Figure 14 1D Acquisition Averaging Parameters Window

Changing the averaging parameters will automatically affect repetition time.

3.2.1.1.4 Timing

In 1D acquisition, not every successive A-Scan is guaranteed. If the repetition time between A-Scans is too high, scans will be lost, and a warning will be displayed.

To avoid timing issues, adjust the repetition time until the warning disappears. Use the repetition time slider or increase one of the averaging parameters.

3.2.1.1.5 Display Toolbar

A-Scan Display

The A-Scan Display shows the spectral raw data and the processed A-Scan data as a line profile. The graphs can be zoomed in and out using the mouse wheel. The data can be fit to the available screen space using the *Fit to Screen* button. The A-Scan to be presented can be selected in the M-scan display. If not specified the most recent A-Scan is displayed.

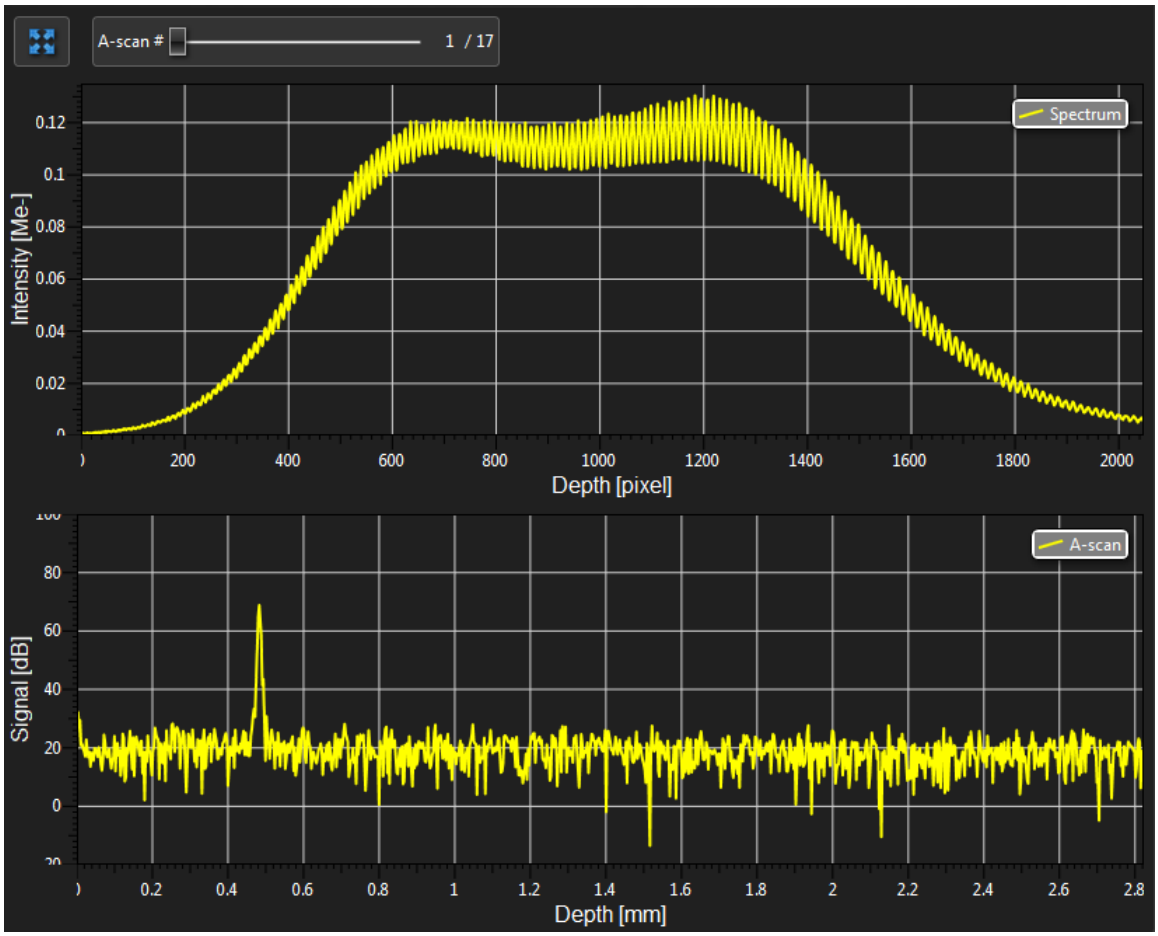


Figure 15 A-Scan Display Showing Spectral Raw Data (Top) and Processed A-Scan (Bottom)

The screenshot above shows spectral raw data (top) and processed A-Scan (bottom). The *Fit to Screen* button is at the top left.

M-Scan Display

The M-Scan Display provides an alternative to the line profile view. Here, depth information is encoded in the vertical axis while time information (A-Scan number) is encoded in the horizontal axis. This is usually also referred to as an M-scan. The dynamic range slider provided here works analogously to the one in 2D acquisition.

Figure 16 A-Scan Button

Pressing the *A-Scan* button toggles the A-Scan slider. A yellow dotted line appears on the M-Scan Display. To select a specific A-Scan, grab the line with the mouse and shift it horizontally to the desired position. A vertical preview of the selected A-Scan will be shown on the right side. Switching back to A-Scan mode will display the selected A-Scan #.

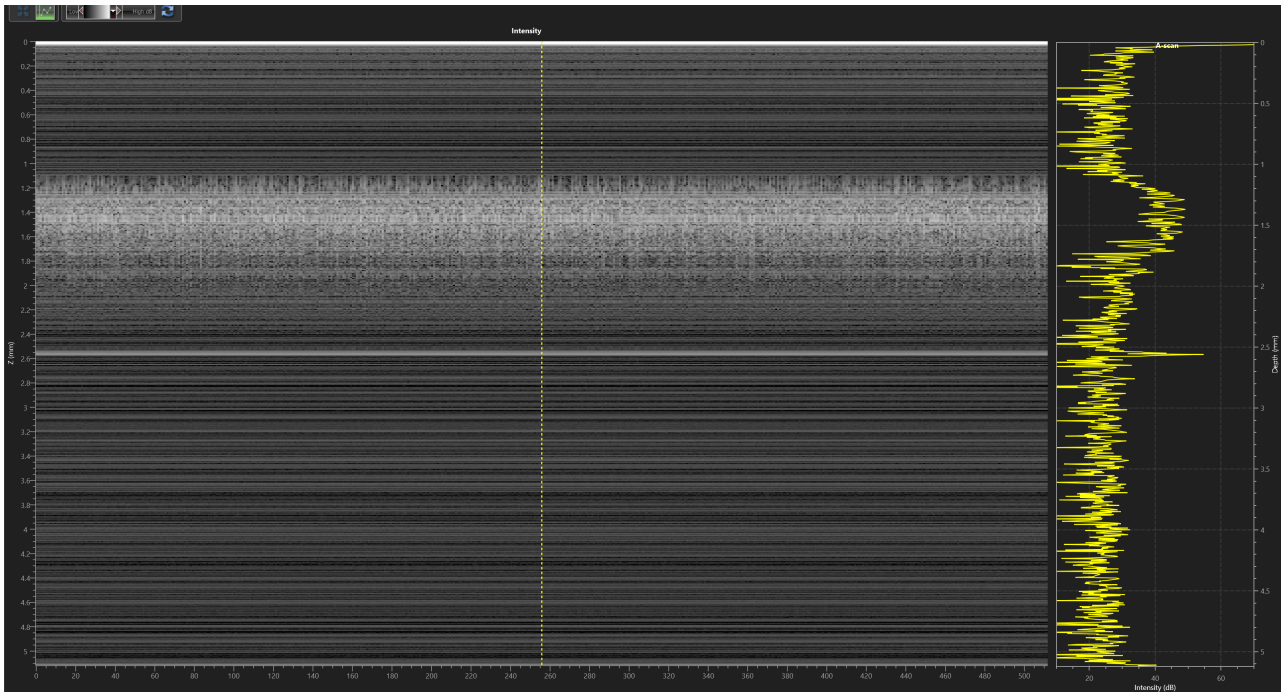


Figure 17 M-Scan Display

To export the selected A-Scan, select *.csv as the output format and check export only displayed A-Scan (see section Standard Export). If export spectrum is checked, both, A-Scan and spectrum are exported as *.csv.

3.2.1.2 2D Acquisition

In 2D Acquisition, the probe beam is scanned in a lateral direction, while reflection profiles (A-Scans) are captured in the depth direction. For further information regarding the processing of an A-Scan, see section 1D Acquisition.

This collection of A-Scans results in a 2D cross-sectional image called a B-Scan. As an alternative to using the scan parameter window, the scan line can also be defined using the draw & scan feature.

3.2.1.2.1 Action Toolbar

The Action Toolbar in 2D Acquisition appears as in the screenshot below.

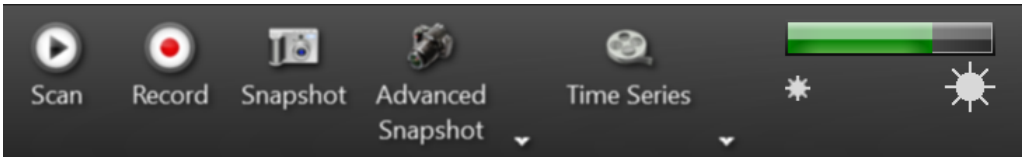


Figure 18 Action Toolbar Options in 2D Acquisition Mode

Scan
Use the *Scan* button to start and stop 2D OCT data acquisition.

Record
Use the *Record* button to acquire a consecutive stack of B-Scans quickly. The stack appears as a single entry in the dataset list and can be viewed by clicking on it.

Snapshot
When the OCT Imaging System acquires 2D data, save a single image using the *Snapshot* button. The acquired B-Scan appears in the dataset list and can be selected for viewing.

Advanced Snapshot
To acquire high-quality 2D data, use the *Advanced Snapshot* button. Press the down arrow next to the *Advanced Snapshot* button to select options for this mode. It offers advanced averaging options for higher quality images. B-Scan averaging registers images to reduce bulk sample motion effects. All parameters, except averaging options, are identical to live data acquisition parameters. Averaging options in the dataset parameters are ignored.

The acquired B-Scan appears in the dataset list and is automatically selected.

Time Series
To acquire multiple advanced snapshots at specific time intervals, use the *Time Series* button. By clicking the down arrow next to the *Time Series* button, the time interval and the number of advanced snapshots are set to be taken. Please note that settings for each individual advanced snapshot are determined by the Advanced Snapshot settings. Each dataset acquired will have its own entry in the Dataset Manager.

Calibration
If the selected probe is configured to skip automatic calibration measurements, the toolbar will provide buttons for calibration of the apodization spectrum. There are two options: the actual scan can be used as calibration, or a manual calibration can be acquired. Please note that the manual calibration cannot be performed during an acquisition.

Figure 19 Alternative Options for Calibration

3.2.1.2.2 Scan Pattern

In the 2D imaging mode, the Scan Pattern can be set by either specifying its parameters or by using the Draw & Scan feature. The Scan Pattern parameters can be found in the Dataset Parameters window.

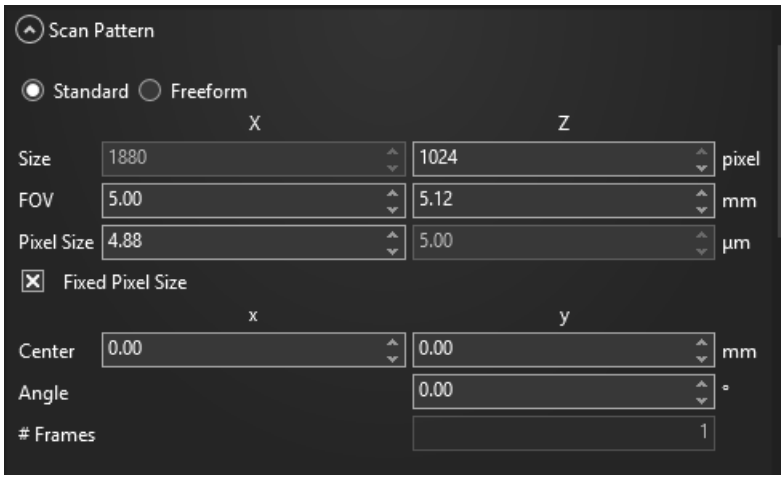


Figure 20 Settings to Define the Scan Pattern

Draw & Scan

The Draw & Scan feature provides an easy way to specify the Scan Pattern in Standard and Freeform mode. A Standard Scan Pattern can be defined by clicking the left *Mouse* button on the start and end points of the B-Scan in the video image. A Freeform Scan Pattern can be defined by clicking the left *Mouse* button any number of times and ending with the right button. On top of the video image, a blue rectangle indicates the maximum scan range, i.e. no portion of the scan may be outside of this rectangle.

Size

The $Size\ X$ specifies the number of A-Scans in a B-Scan while $Size\ Z$ is the number of depth pixels in each A-Scan. The measurement depth shown under $FOV\ Z$ depends directly on the number of pixels in the A-Scan. If the number of pixels is reduced, the imaging depth reduces as well. By increasing the number of A-Scans in a B-Scan ($Size\ X$), the imaging quality can be increased, however, imaging will become slower.

Please note that increasing the $Size\ X$ parameter will only make sense as long as the X spacing remains below or equal to the lateral resolution of the system, which in turn depends on the type of OCT Imaging System and probe objective. Oversampling/averaging can be controlled by averaging in the Dataset Parameters window.

Field of View (FOV)

The parameters in FOV determine the scan length of the B-Scan ($FOV\ X$) and the maximal imaging depth ($FOV\ Z$). The former parameter can be automatically set by using the draw & scan feature.

Pixel Size Parameters/Fixed Pixel Size

The Pixel Size Parameters specify the pixel dimensions along the respective axes. When *Fixed Pixel Size* is checked, the spacing parameter is enabled, and the size parameter for the X-axis is disabled. The pixel size is then automatically adjusted, maintaining the X-axis pixel size when the field of view is changed.

Center

The physical coordinate of the Center of the B-Scan can be specified by the x and y coordinates, where the reference point is the Center of the maximum scan range rectangle.

 # Frames

The parameter # Frames holds the number of captured B-Scans. The following parameters are available in Freeform Scan Pattern mode only and will appear below the standard Scan Pattern parameters by enabling the Freeform Scan Pattern mode.

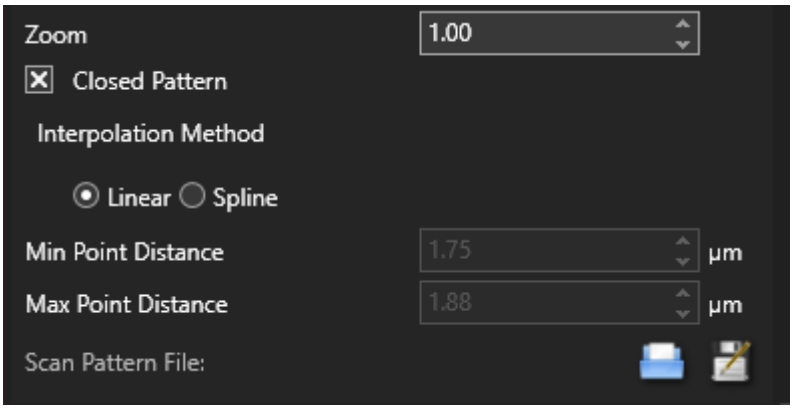


Figure 21 Settings to Define the Scan Pattern (Freeform Scan Pattern Mode Only)

Note that the Freeform Scan Pattern mode is not available for the handheld probe at this time.

Angle

The Angle of the B-Scan can be specified by the Angle parameter. The scan direction is rotated by increasing/decreasing the value.

Zoom

The length of the Freeform Scan Pattern can be increased and decreased with the Zoom parameter. The Zoom is applied around the center of mass of the scan pattern points, e.g. changing the Zoom for a circle shaped scan pattern will result in a circle with increased/decreased radius without changing its position. The same behavior will occur for other arbitrary shapes of a scan pattern.

Closed Pattern

Enabling the Closed Pattern parameter will connect the start and end point of the Freeform scan pattern.

Interpolation Method

The points of the Freeform scan pattern are the edge points used for the interpolation to create a scan pattern with almost equidistant sampled scan points. For these two interpolation methods, linear and spline, are available.

Min Point Distance and Max Point Distance

Since the sample points of a Freeform scan pattern are not perfectly equidistant any more due to interpolation reasons these two parameters show the minimal and maximal distance between two adjacent scan points in the scan pattern.

Scan Pattern File

With the Scan Pattern File function, it is possible to load and save predefined Freeform scan patterns. It is possible to create .txt files with other programs, e.g. notepad, following the format and use those predefined scan patterns in the ThorImage®OCT. The .txt file needs to have the x-coordinates and y-coordinates in mm in the first and second column and the scan indices which specify the belonging B-Scan in the third column. For a B-Scan or a volume pattern, all scan indices need to be zero. The SDKs support more scan patterns; please see the chapter Software Development Kits for more information. The following image shows an example .txt file.

```
X          Y          ScanIndex
0.5        -0.2886751346    0
0          0.5773502692     0
-0.5       -0.2886751346    0
```

Figure 22 .txt File Containing Scan Points and Scan Indices for a Freeform Scan Pattern

3.2.1.2.3 Recording

In Recording options, one can specify the number of B-Scans that are recorded when pressing the *Record* button in the action toolbar. By default, the number of recorded frames is not limited. When selecting the *Stop recording after* check-box, one can specify the number of frames that are recorded.

Recording can be automatically stopped after a predefined number of frames.

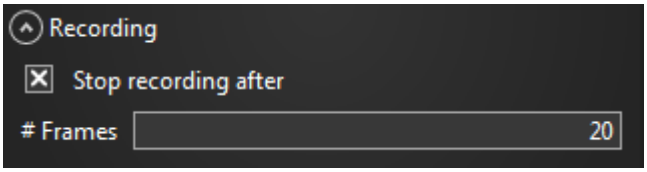


Figure 23 Recording Tab of the ThorImage®OCT

3.2.1.2.4 Display Toolbar

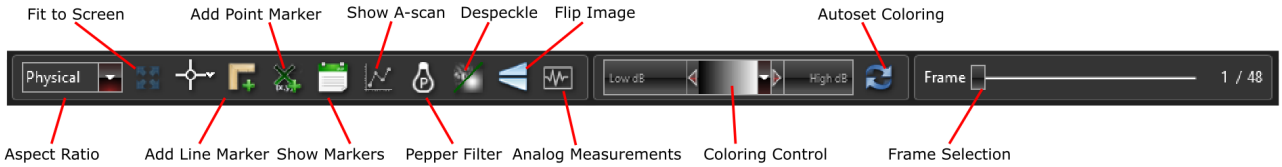


Figure 24 Display Toolbar Settings for the 2D Display

The Display Toolbar provides control over the settings affecting the way in which B-Scan OCT data are viewed. It contains various options to influence the aspect ratio of the display, perform length measurements of structures in the B-Scan, or to display a single A-Scan of the B-Scan. Additionally, the Display Toolbar provides controls to adjust the coloring parameters, such as the contrast and the brightness of the OCT image.

Aspect Ratio

This drop-down box sets the Aspect Ratio of the B-Scan. The following options are available:

- **Physical**
  The physical Aspect Ratio is used. The image size depends on the scan pattern FOV parameters.
- **Pixel**
  The Aspect Ratio depends on the number of A-Scans in the B-Scan and the number of depth-pixels. In this mode, the image pixels are quadratic.
- **Stretch**
  The maximum available display space is used, ignoring the size relations of the actual scan pattern.

Zoom

By using the mouse wheel anywhere on the screen, the region can be zoomed in and out.

Fit to Screen

When the Fit to Screen button is pressed, the size of the displayed B-Scan will be adjusted such that it fits on the screen while maintaining the current aspect ratio. The image will be entirely zoomed out.

Show Axes

By default, the ThorImage®OCT will show axis labels indicating the scale of each axis on 2D plots. This can be disabled by using the *Show Axes* button.

Show Cursor

Clicking the *Show Cursor* button will cause the ThorImage®OCT to display a drop down panel. When the mouse pointer is moved over the 2D display, this panel will display information about the data at the location of the mouse pointer.

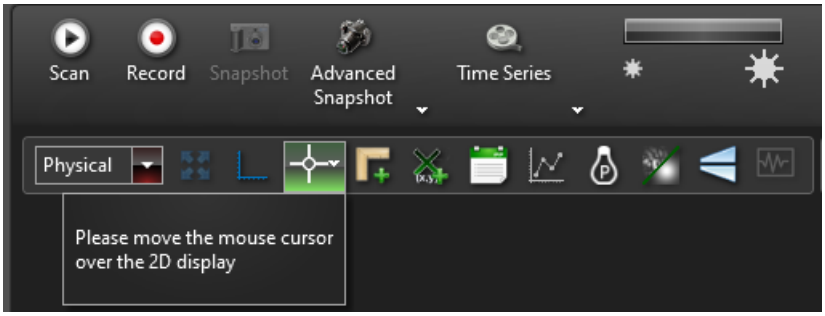


Figure 25 2D Display Data Cursor

The drop down contains the position of the mouse cursor in pixels and physical coordinates and the value of the OCT data point under the mouse cursor.

Marker Tool

The Marker Tool serves to measure the size of structures that appear in the B-Scan. Clicking either the *Add Line Marker* or *Add Point Marker* button activates the marker tool. With *Add Line Marker* active, a click anywhere on the B-Scan defines the start point of the measurement and a second click on the B-Scan defines its end point. *Add Point Marker* creates a single-point marker when clicking into the B-Scan.

Figure 26 Marker Tool Buttons (From Left to Right: Add Line Marker, Add Point Marker, Show Markers)

The length of the marker is shown directly in the B-Scan. Clicking the *Show Markers* button opens a window showing all added markers with their respective coordinates, their line length, and their angle to the x-axis. From this window you may delete markers, change their color, and export the marker list to a .csv file by clicking the *Export* button.

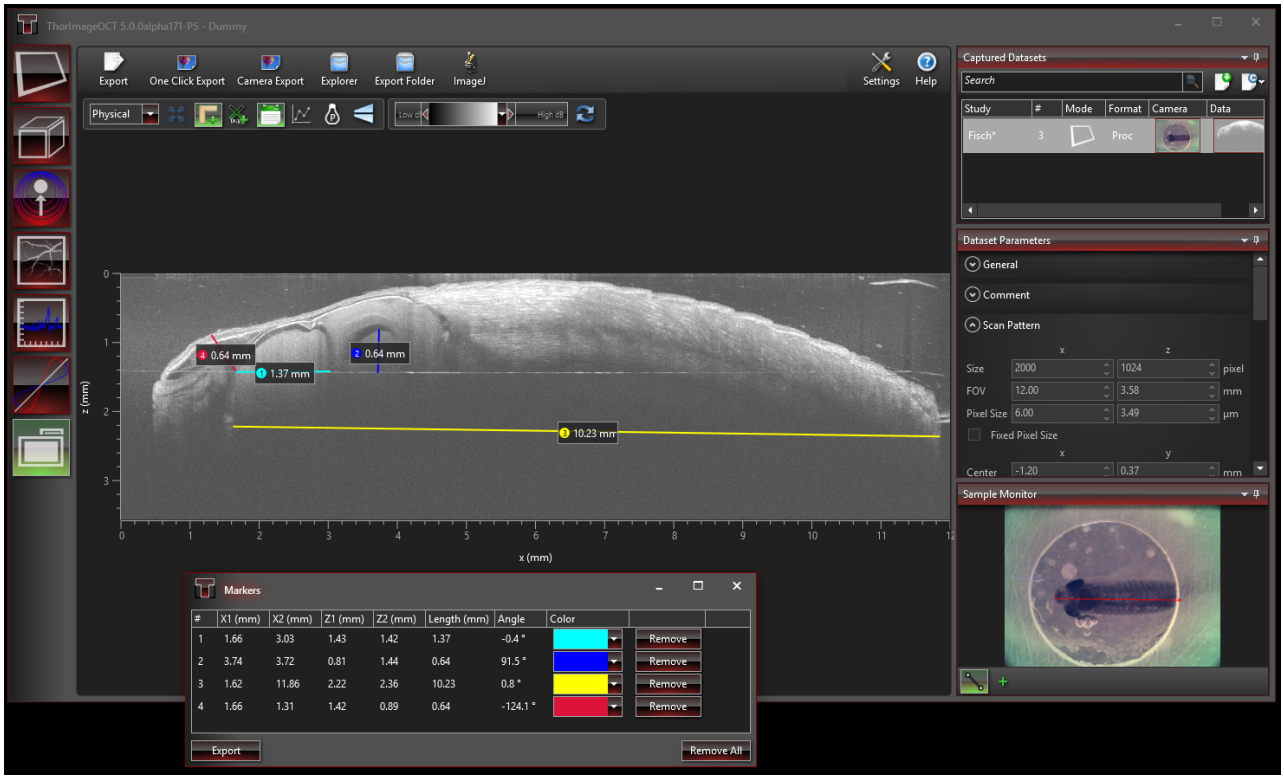


Figure 27 Performing Length and Angle Measurements by Adding Markers to the Image in 2D Acquisition

Note that the refractive index of the sample also affects the measurement results. It can be adjusted in the General settings.

Marker Profile

The Marker Profile feature lets you display the OCT data along a line marker in the OCT data, additionally finding peaks along the displayed OCT profile.

The following image shows an OCT profile along a line marker together with the primary peak data.

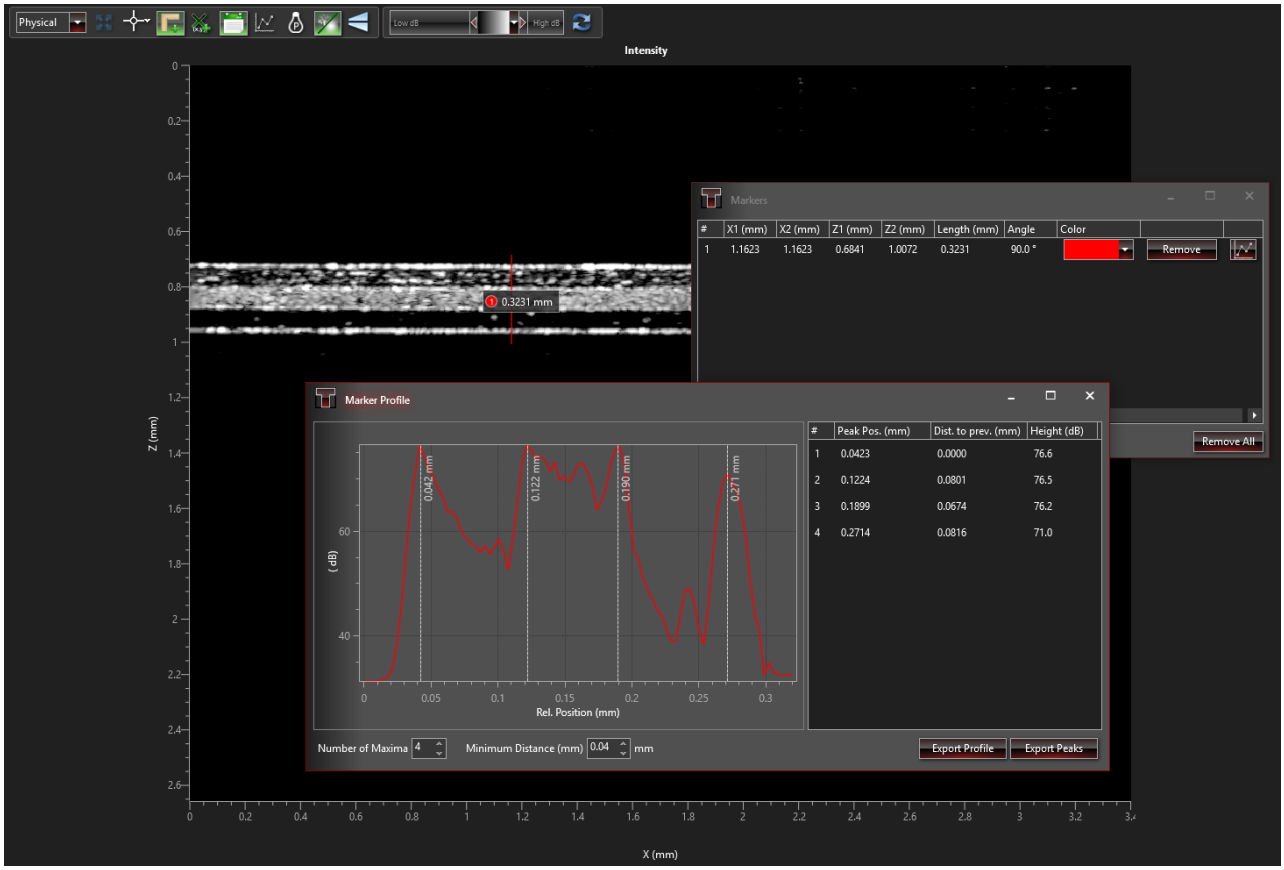


Figure 28 Marker Profile Window (OCT Profile Along a Line Marker Together with its Primary Peak Data)

To open the Marker Profile window, at least one line marker will have to be drawn. Open the Marker Profile window and click the G*raph Symbol* button on the right of the line marker's list entry with the (see image above).

Within the Marker Profile window the respective data plot as well as the its detected peak positions are shown. The list to the right of the profile display shows the data for all peaks (local maxima) within the OCT profile shown. These values include the peak position and its distance to the previous detected peak (both in mm) and the peak height in dB. The number of displayed peaks can be controlled by the Number of Maxima numeric control in the lower left; the first peak will be the highest, the second will be the second highest etc.. Only peaks within a certain minimum distance along the line marker will be displayed; this distance can be set by the Minimum Distance (mm) control next to the Number of Maxima control.

A-Scan View

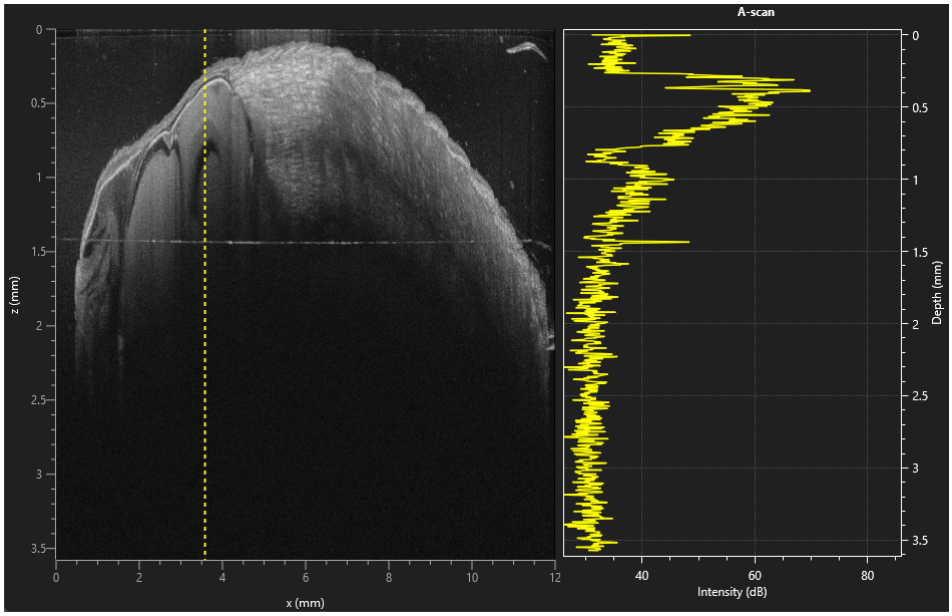


Figure 29 A-Scan View in the 2D Display

When the A-Scan view is activated, a single A-Scan of the B-Scan at the position of the vertical red line that is shown in the B-Scan will be displayed. Moving the line with the mouse selects the A-Scan to be displayed.

In the A-Scan view, the x-axis is the signal strength in dB and the y-axis is the depth in mm. The range of the x-axis is determined by the dynamic range that is set in the coloring control.

Pepper Filter

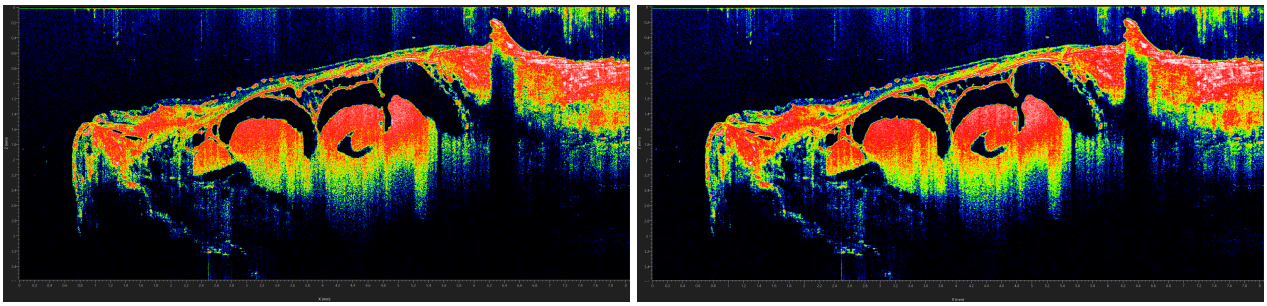


Figure 30 (Left) Measured B-Scan of a Zebra Fish
Figure 31 (Right) Measured B-Scan of a Zebra Fish With Pepper Filter

The Pepper Filter searches the displayed image for bright and dark spots which mostly occur due to speckle and noise in the acquired data. It removes them based on the surrounding data values and can thus improve the visual appearance of the B-Scans. The Pepper Filter will not have any influence on exported images or data but merely improves the visual appearance within the ThorImage®OCT.

Despeckle Filter

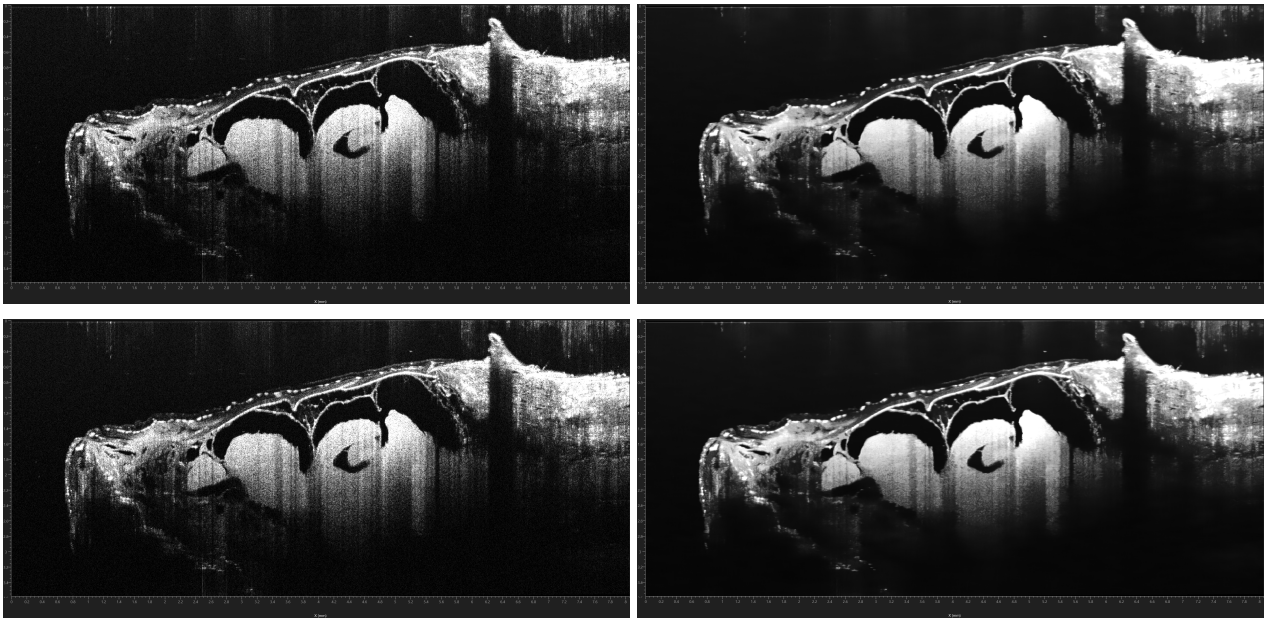


Figure 32 (Left) Measured B-Scan of a Finger Tip
Figure 33 (Right) Measured B-Scan of a Finger Tip With the Despeckle Filter

OCT is an imaging technique that makes use of coherent light and, as such, images are subject to speckle noise. ThorImage®OCT *Despeckle Filter* is designed to reduce speckle noise in images without compromising details in the imaged structures; this improve the visual appearance of the B-Scans.

Please note that the *Despeckle Filter* is computationally expensive. As a result, the PC and system performance may be reduced significantly when the *Despeckle Filter* is active. For older PC hardware, the *Despeckle Filter* may not be available and will be grayed out.

Flip Image

Flip Image inverts the z-axis of the displayed B-Scan. In general, images can be acquired upside-down when using OCT, as positive and negative time delays cannot be distinguished. If this is the case, the *Flip Image* button orients the image back to its physical orientation.

The upside-down imaging can also be used deliberately, as imaging quality in general lowers in large imaging depth. By putting the upper structures in the lower imaging regions, sometimes better images can be achieved.

Note that this option is only available in two-dimensional B-Scan display and in two-dimensional polarization-sensitive mode.

Analog Measurement Data Visualization

Figure 34 Analog Channel Selection in 2D Display Toolbar

On devices supporting acquisition of analog signals, a 2D OCT-scan may contain an additional 1D analog dataset whenever at least one analog channel is enabled in the Dataset Parameters. For details, see the section Analog Measurements.

When the *Analog Input View* button is activated, the captured 1D data from the analog measurement will be available for display. Use the drop down menu on the right side of the 2D display toolbar to select the

analog channel to visualize. The channel dropdown will not be visible if the dataset does not contain analog data.

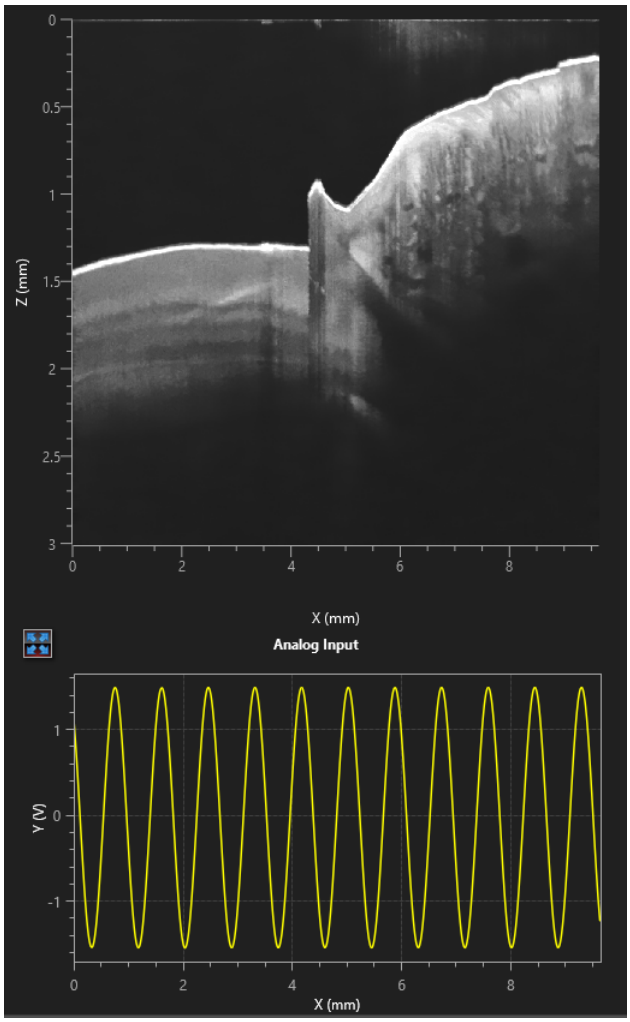


Figure 35 Analog Data Visualization in the 2D Display

In the analog input view, the x-axis range is determined by the corresponding 2D OCT data.

Coloring Control

The Coloring Control specifies the dynamic range and the colormap that is used for creating false color images. By adjusting the position of the left and right slider button (,), the dynamic range can be increased or decreased. As the distance between the buttons increases, the contrast of the images decreases. By moving the entire slider, the brightness of the images can be controlled.

Right-clicking the *Coloring Control* brings up a popup menu where the desired colormap can be selected.

Clicking the *Blue Arrow* symbol will set the dynamic range to a reasonable default value depending on the average intensities of the currently acquired image.

Figure 36 Coloring Control Panel

Right-click on the *Coloring Control* Panel to open the colormap popup.

Frame Selection
If a 2D dataset contains more than one B-Scan, the frame slider can be used to scroll through the single B-Scans in the dataset, displaying each in the 2D display.

3.2.1.3 3D Acquisition

In 3D Acquisition, 3-dimensional OCT-scans can be acquired. In order to achieve this, the scan pattern contains a stack of B-Scans. The 3D Acquisition is best suited for samples with little movement since the measurement usually takes some time depending on the number of A-Scans per B-Scan and B-Scans per volume taken. As an alternative to using the scan parameters window, the scan region can be defined by using the draw & scan feature.

3.2.1.3.1 Action Toolbar

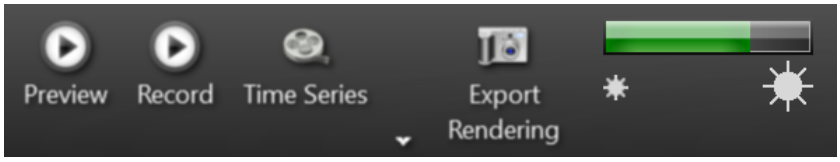


Figure 37 Action Toolbar Options in the 3D Acquisition Mode

Preview
The 3D acquisition provides a *Preview* button that can be used to rapidly acquire 3D volumes at a very fast rate. In this mode, multiple volumes are acquired and visualized online in the 3D display until the acquisition is stopped by the user. The data that is acquired using the preview mode is not stored on disk. Use the *Record* button to create high quality OCT images of the examined samples.

Note that the size of the preview dataset is defined in the *Preview* group of the *Dataset Parameters* control. This size will generally be significantly lower than the actual volume acquisition size applied when using the *Record* button.

Record

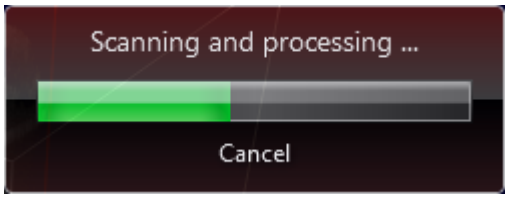


Figure 38 Scan Progress and Cancel Button

The *Record* button can be used to acquire a single volume with the scan pattern and resolution specified in the dataset parameters. It is used for single shot acquisition.

During the scan, a progress bar with a *Cancel* button is shown. The current acquisition can be stopped by pressing the *Cancel* button.

Time Series
Using the *Time Series* button, one can invoke a series of 3D measurements. In the drop-down list of the button, one can adjust the number of volumes to be acquired and the scan pause between successive volumes. Note that for each measured volume, a new 3D dataset is created.

Note that the minimum available scan pause time is limited by the time calculated for a single scan/storage process.

Export Rendering
Using the *Export Rendering* button, one can export the currently displayed volume rendering as a single image, much like a screenshot of the display area.

3.2.1.3.2 Scan Pattern

In the volume imaging mode, the Scan Pattern can be set by either specifying its parameters in the dataset parameters control or by using the draw & scan feature.

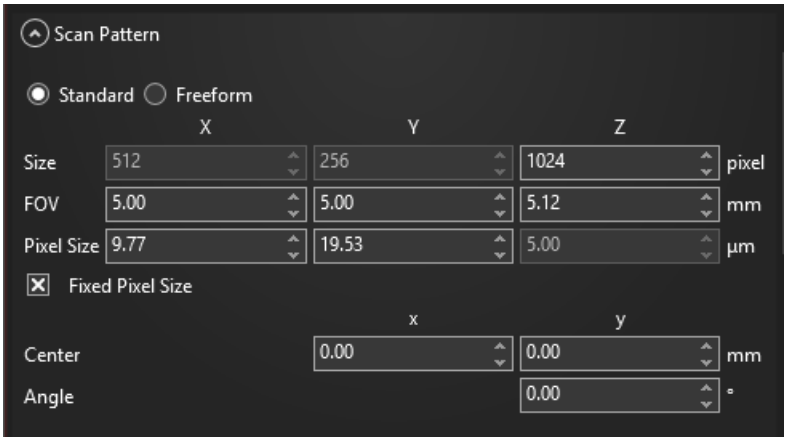


Figure 39 Parameters to Specify the Scan Pattern in 3D Acquisition

Draw & Scan
The Draw & Scan feature provides an easy way to specify the scan pattern by clicking two opposing corners of the volume in the video image. In the video image, a blue rectangle indicates the maximum scan range. No portion of the scan region may be outside of this rectangle.

Size
$Size\ X$ specifies the number of A-Scans in a B-Scan whereas $Size\ Z$ specifies the numbers of B-Scans in the volume, and $Size\ Z$ gives the number of depth pixels in an A-Scan. The product of the three sizes specifies the number of pixels to be acquired in the complete volume. The measurement depth shown under $FOV\ Z$ depends directly on the number of pixels in the A-Scan. If the number of pixels is reduced, the imaging depth reduces as well. By increasing the number of A-Scans in a B-Scan ($Size\ X$), the imaging quality can be increased, however, imaging will become slower.

Please note that increasing the size X or size Y parameter is only effective if the X and Y pixel sizes are below or equal to the system's lateral resolution, which depends on the OCT Imaging System type and probe objective. Oversampling or averaging is controlled via the averaging parameters in the dataset parameters.

Pixel Size Parameters/Fixed Pixel Size
The Pixel Size Parameters indicate the pixel dimensions in the respective axes. Checking Fixed Pixel Size enables the Pixel Size Parameter and disables the Size Parameter for the X- and Y-axis; the pixel size is adapted automatically, keeping the X- and Y-axis pixel sizes when changing the field of view.

Field of View (FOV)
The parameters in FOV determine the scan length ($FOV\ X$), the scan width ($FOV\ Y$), and the imaging depth ($FOV\ Z$) of the imaging volume. The former two parameters can also be set by using the draw & scan feature.

Center
The physical coordinates of the lateral Center of the volume can be specified by the X and Y coordinates, where the reference point is the center of the maximum scan range rectangle.

Angle

The Angle of the volume can be specified using this parameter. The scan direction is rotated by increasing/decreasing the value.

Enabling the Freeform scan pattern mode in 3D will lead to a scan pattern which scans a volume of any user-defined form. It is possible to draw the inner border of the scan pattern with the draw & scan behavior described in the section Scan Pattern. The outer border is created with an inflation of the inner border in the normal direction of the drawn line at the single scan points on the inner border. The scanning region will be the region between the inner and outer border of the Freeform pattern. The $FOV\ Y$ determines here the distance from the inner to outer border in normal direction. The $Size\ Y$ defines how many scans are used within the specified region. E.g. scanning an annulus here means the $Size\ x$ will be the number of A-Scans on one single circle of the annulus and the $Size\ Y$ is the number of circles which is used to define the annulus.

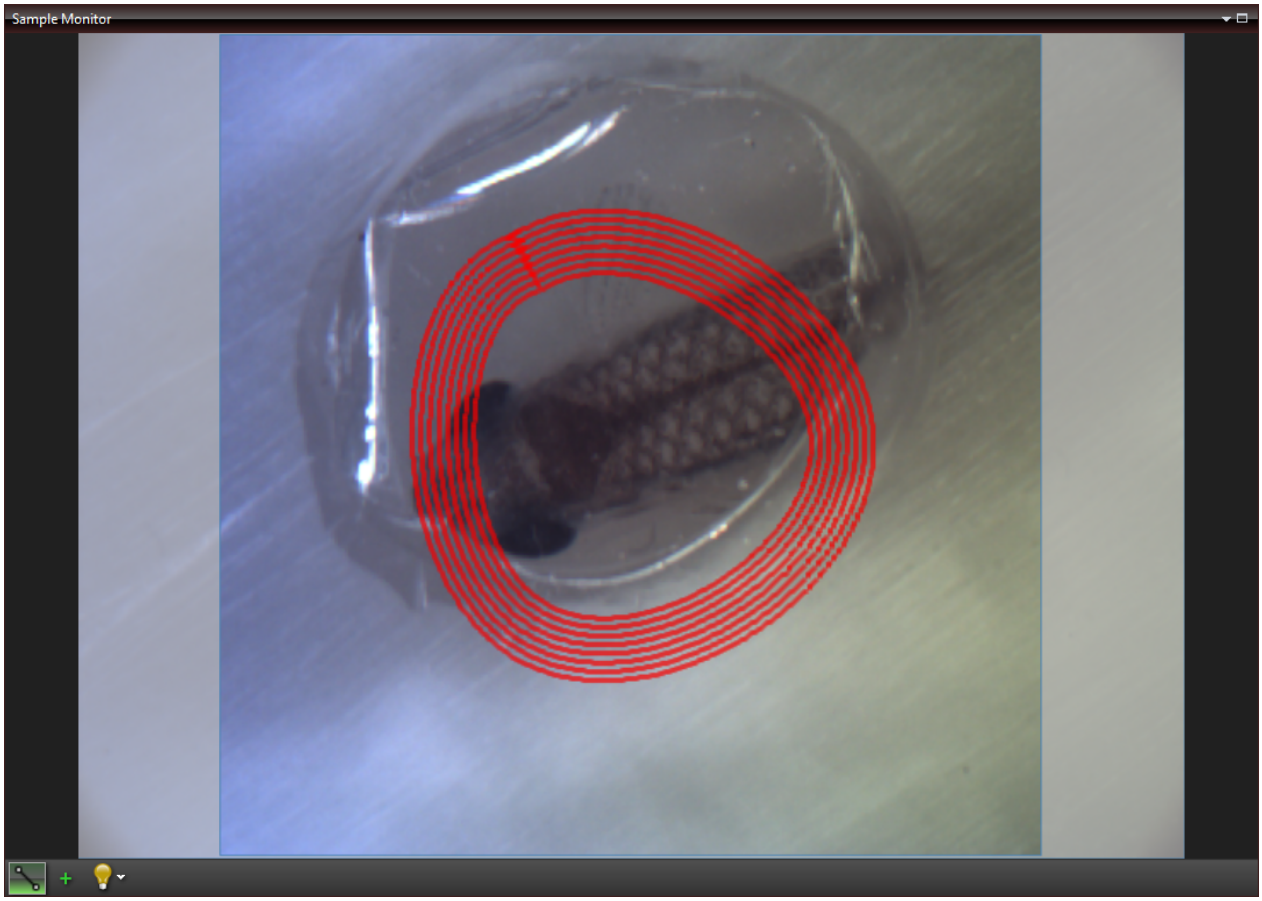


Figure 40 Scan Pattern Defined with a Volume "Freeform" Scan Pattern

The red lines show the scan pattern defined with a volume Freeform scan pattern. A volume pattern consists of several B-Scans which are the single drawn lines, e.g. with $Size\ Y$ set to eight in the picture shown above.

Please note that the Freeform scan pattern is not available for the handheld probe right now.

3.2.1.3.3 Display Toolbar

ThorImage®OCT provides capabilities to render volumetric OCT data with different view options.

In general the 3D view can be manipulated using the mouse:

- **Animate Rotating**
  Moving the mouse while holding the left *Mouse* button, the volume can be rotated.

- **Translation**
  Moving the mouse while holding the right *Mouse* button, the volume can be shifted laterally.
- **Zooming**
  Using the mouse wheel, the volume can be zoomed in and out.

Display Toolbar

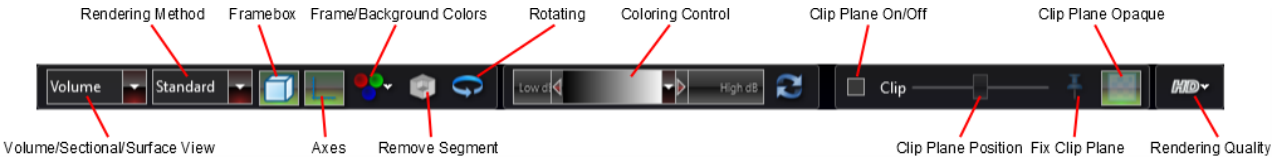


Figure 41 Display Toolbar Settings for the 3D Display

Using the *frame/background* drop-down menu, the top and bottom *background colors*, as well as the color of the *framebox* and *scalebars* can be specified.

With the animate *Rotating* option, the currently displayed volume revolves around the z-axis. The rotation is toggled by the *Rotating* button.

The coloring control behaves as described in the section Coloring Control. By clicking on the first *drop-down box*, one can switch between the *Volume View*, the *Sectional View*, and the *Surface View*. Both are described in the following sections.

Views

3D Datasets can be visualized in different views:

- Volume View
- Sectional View
- Surface View

Volume View

The Volume View displays a 3D rendering of the acquired dataset.

Rendering Methods

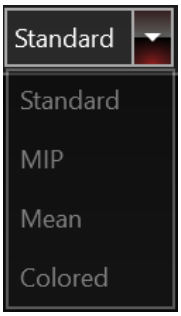


Figure 42 Available Rendering Methods in Volume View

The Volume View offers three different Rendering Methods.

Depending on the properties and composition of the sample, different rendering methods provide different advantages as to the aspects of sample inspection. All of these use the raycasting principle.

- **Standard Mode**
  Attenuates the Projected Ray Through the Viewing Plane
- **MIP (Maximum Intensity Projection)**
  Displays the Data Point of Highest Intensity in the Viewing Direction

- **Mean Method**
  Uses the Mean Intensity Value

Colored is a variant of standard mode, used to overlay additional data from the Analog Measurements onto the 3D OCT volume. See the section Analog Data Visualization for details.

Clip Plane

Figure 43 Clip Plane Controls

The Clip Plane is activated by checking the *check-box* in the Clip Plane controls.

Using the Clip Plane makes parts of the volume transparent. By default, the transparent part of the volume is always perpendicular to the view direction and can be moved along the viewing axis by using the clip plane slider. Clicking the *Pin Icon* locks the clip plane to the volume. The *Transparency* button to the right toggles the clip plane's opacity on or off.

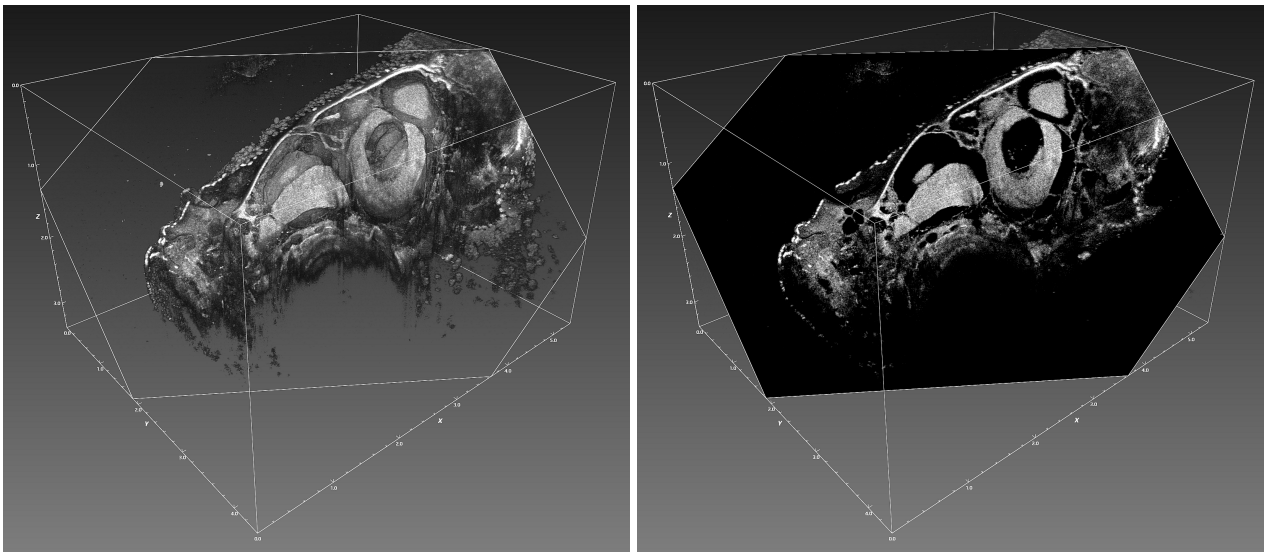


Figure 44 (Left) Clip Plane Using the Transparent Mode
Figure 45 (Right) Clip Plane Using the Opaque Mode

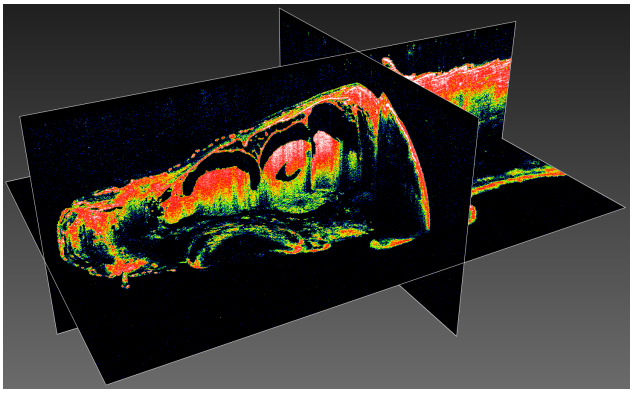
Dynamic Resolution

Rendering large volumes will require significant resources from the GPU of the system. To maintain interactive framerates when the display is manipulated (rotated, zoomed, etc.), the ThorImage®OCT will automatically show a low-resolution preview. As soon as the interaction is stopped, the full resolution image will be rendered. This behavior can be disabled in the settings dialog.

Sectional View

The sectional view displays single slices in each major axis of the 3D volume. The individual slices can be switched on and off using the corresponding check-boxes in the display toolbar. The position of the displayed slices can be adjusted with the sliders in the display toolbar.

Figure 46 Sectional View Parameters in the Display Toolbar of the 3D Volume Display



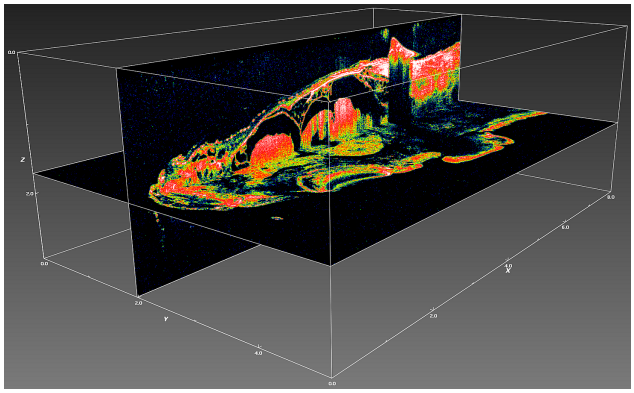


Figure 47 (Left) ***Sectional View Mode of 3D Display (All Three Sections)***
Figure 48 (Right) ***Sectional View Mode of 3D Display (Without XZ Section)***

Surface View

The Surface View performs a simple segmentation of the outer surface of the object viewed in the OCT section. The surface is then rendered with an additional color between red and white indicating the actual depth.

Depth Coloring Control

The Depth Coloring Control can be used to specify the region of depths that are used for the color-coding of the depth in the rendered volume.

Median Filter

A Median Filter can be applied to reduce the effect of noise, e.g., speckle noise, on the segmented OCT data surface.

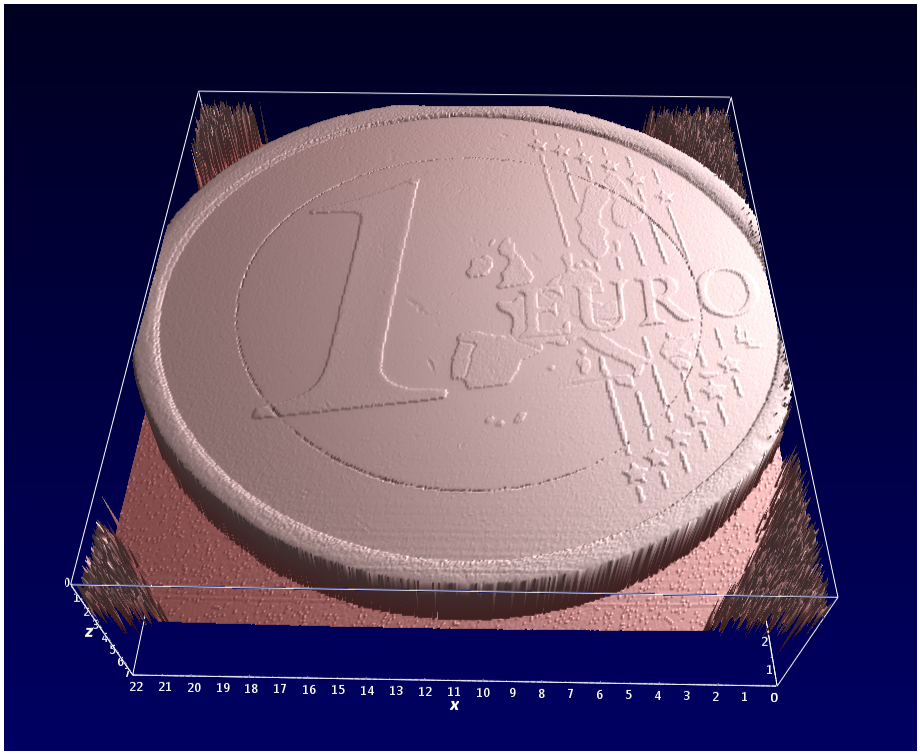


Figure 49 ***Surface View Mode of the 3D Display***

Analog Measurement Data Visualization

On devices which support analog measurements acquisition, there may be additional 2D data sampled from analog input channels which can be rendered along with the 3D volume. This is supported by the colored volume rendering mode, which can be enabled from the rendering mode dropdown:

Figure 50 Available Rendering Methods in Volume View

In this mode, the data from an analog channel will be overlaid onto the 3D volume. This is achieved by multiplying each point of the 3D OCT data with the corresponding value of the analog data. Since the analog data has no depth information, an analog sample at a given X and Y scan position will be multiplied onto the entire depth of the A-Scan at this location.

Colored mode uses a second color palette for the intensity of the analog data and multiplies the color values of analog data and OCT data. Therefore, this mode works best when selecting a grayscale palette for the OCT data.

The image below shows the 3D view of a strawberry where an analog signal has been simulated at the seeds:

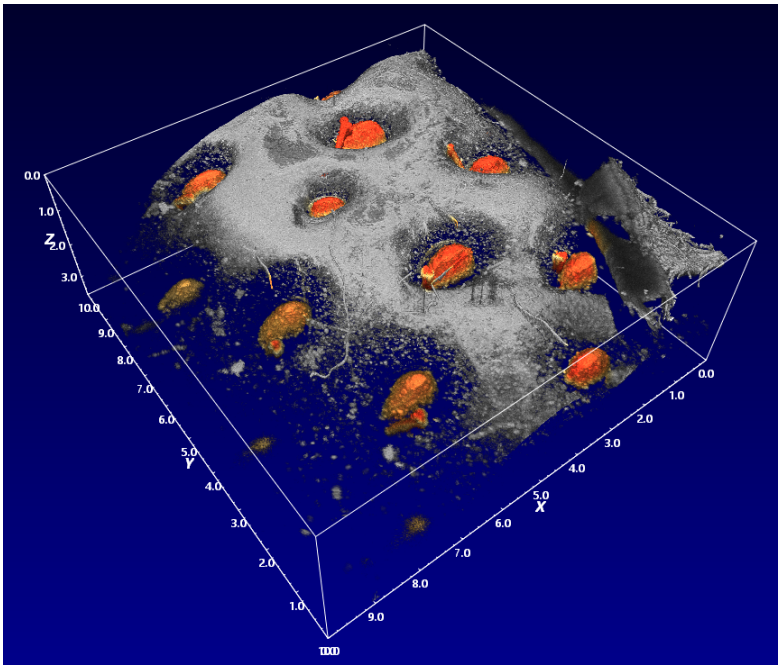


Figure 51 3D Image of a Strawberry with Overlaid Data from Analog Channel (Orange-Colored Regions)

When Colored rendering mode is selected, the following toolbar will be displayed and can be used to adjust the rendering of the analog data:

Figure 52 Coloring Toolbar for Analog Data

- The drop down menu on the left can be used to select which analog channel to render. If the dataset does not contain analog data, this menu will be empty.
- The slider in the center can be used to adjust the color scheme of the rendering and adjust the range of the displayed values. By default, the full range of the analog input channel from -10 V to +10 V is used.
- The drop down menu on the right can be used to automatically adjust the display range to the dataset or to change the display value limits to fit the displayed data. For example, if you know that your data only contains values from 0 V to 1 V, fine-tuning the rendering is cumbersome when the base range is -10 V to 10 V. Using the menu, you can set the Range Minimum to 0 V and the Range Maximum to 1 V. The slider can then be used for a much more fine-grained control of the display.
- The *Reset* button will restore the Range Minimum, Range Maximum and selected range to their default values.

Frame Box & Scale Bar

By default the volume is surrounded by a frame box and scale axes are shown for each axis (x, y, and z). These may be toggled on/off.

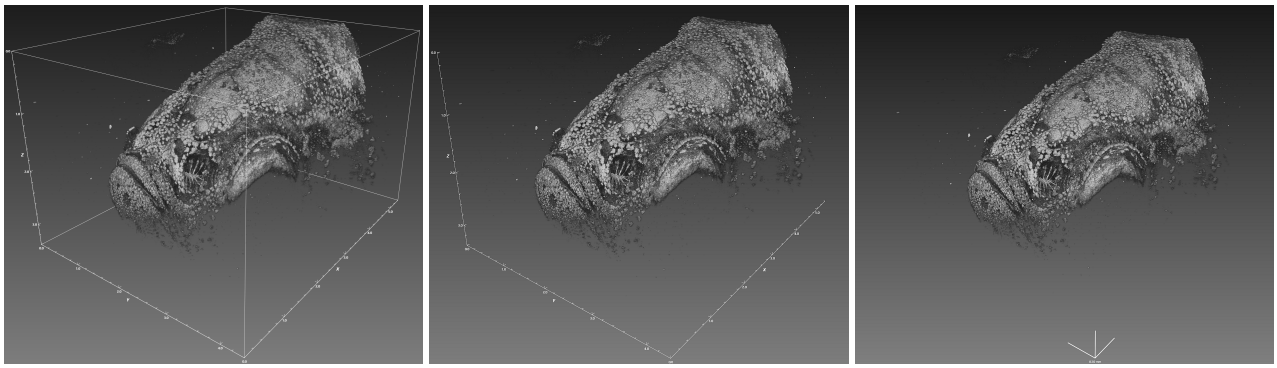


Figure 53 (Left) Frame Box and Scale Bar are Shown
Figure 54 (Center) Scale Bar is Shown
Figure 55 (Right) Frame Box and Scale Bar are Hidden

Normal Views

In the upper right corner of the 3D display there are three buttons which can be clicked to activate a normal view. Clicking the icon again will reverse the orientation.

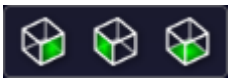


Figure 56 No Normal View is Active

Figure 57 XY Normal View is Active

3D Slice Display

The 3D Slice Display can be activated in the action toolbar of the data viewing mode. It provides two-dimensional views of slices of an entire 3D-volume along the three orthogonal axes, x, y, and z. The corresponding display toolbar for the 3D Slice Display toolbar looks as follows:

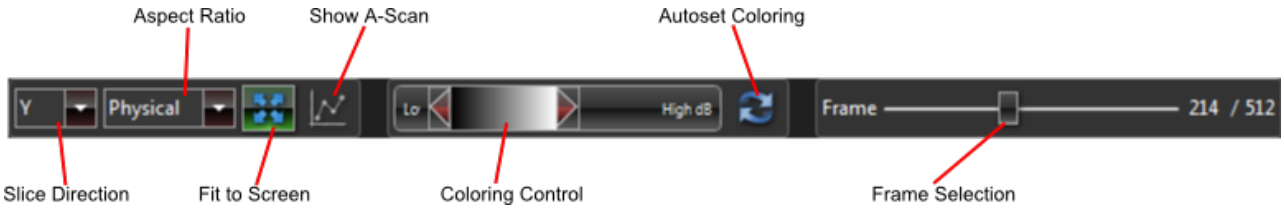


Figure 58 Display Toolbar Settings for the 3D Slice Display

An example of an en-face image in the slice display is shown below.

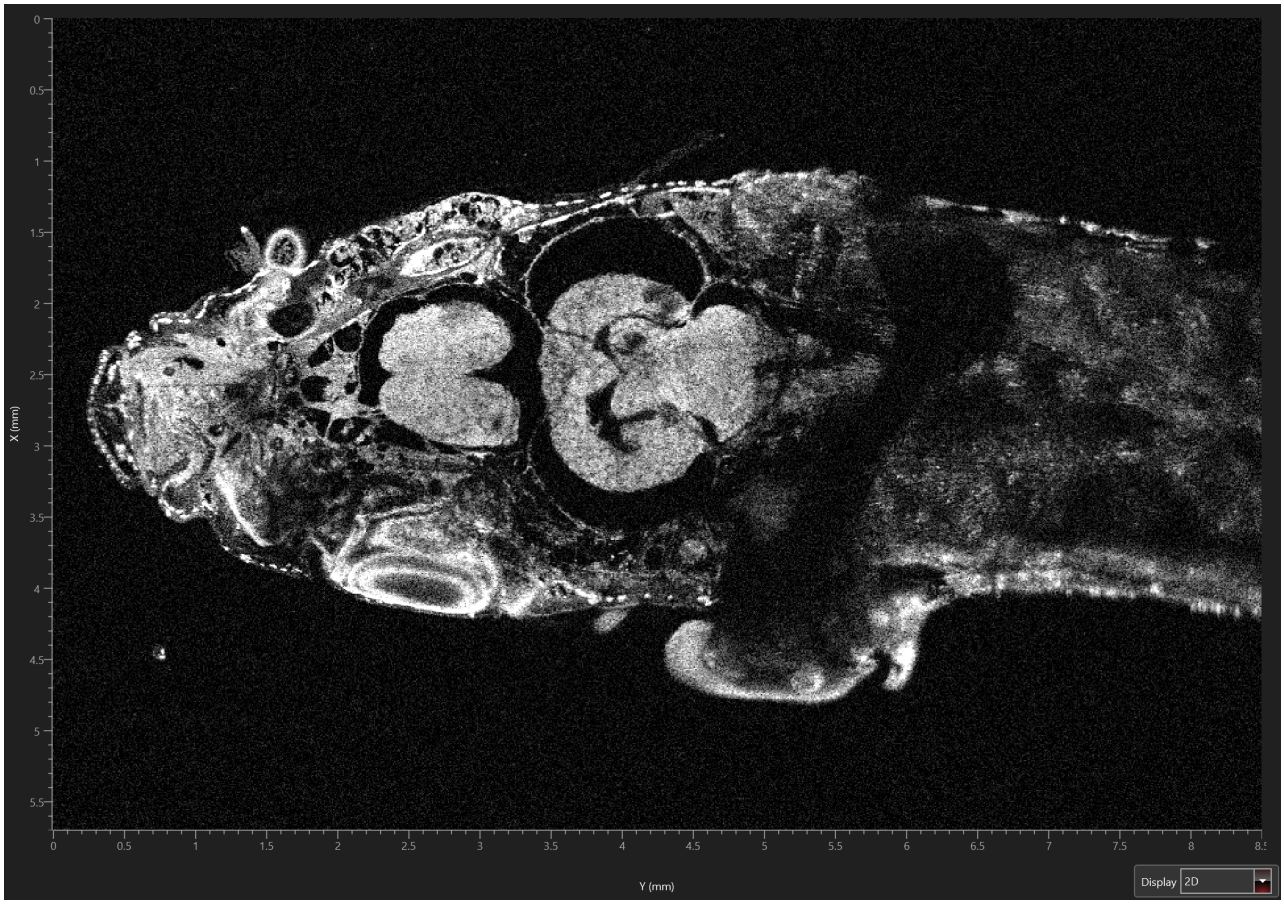


Figure 59 En-face View of a Volume Shown in the 3D Slice Display

The options Aspect Ratio, Fit to Screen, A-Scan View and the Intensity Coloring Control are identical to that in the 2D acquisition display.

Slice Direction

The Slice Direction specifies the axis along which the three-dimensional volume is sliced. B-Scans along the fast (X) and the slow axes (Y) can be viewed, as well as en-face images of the volume (Z).

Frame Selection

The Frame Selection specifies the position of the visible frame within the volume. By moving the slider, different slices along the specified axis (slice direction) can be viewed.

3.2.2 Doppler Acquisition Mode

Doppler Acquisition Mode is used to measure flow velocities of scattering structures, i.e. in addition to structural B-Scan data, as available in 2D acquisition, this method uses additional post-processing to extract phase differences between successive A-Scans. The flow velocities will be colored using a red/blue color scheme, where blue and red indicate the maximum positive and negative flow velocity in scanning direction, respectively. The maximum absolute flow velocity v_{max} can be computed by

$$v_{max} = f\frac{\lambda}{4},$$

where f is the A-Scan rate of the system and λ is the central wavelength. The effective A-Scan rate f can be adjusted directly by changing the device speed. The effective A-Scan rate is further reduced by dividing the A-Scan rate of the device by the spectrum averaging parameter.

Usage of Doppler Acquisition Mode is similar to 2D acquisition.

Note that, due to the nature of the OCT-Scan, only the phase shift component in the direction of the beam can be detected. This does not pose a problem for blood flow observations, since a vector component parallel to the beam direction is present in general. However, quantitative results depend on the direction of blood flow with respect to the beam direction, which is unknown to the OCT Imaging System.

The velocities that can be detected using Doppler imaging depend on the acquisition speed (A-Scan rate) and on the angle between flow velocity vector and detection beam. If the detection window and the actual velocity do not match, it is oftentimes advantageous to adjust the acquisition speed of the OCT Imaging System. The faster the acquisition rate, the higher the velocities that can be detected. However, acquisition speed should approximately correspond to the highest expected axial velocity, in order to optimally detect lower velocities. Acquisition speed is modified by setting the device speed and/or the spectrum averaging parameter. The device parameters influence the physical acquisition speed of the device, while the effective acquisition speed of the OCT device is further reduced by the spectrum averaging parameter.

3.2.2.1 Action Toolbar

The Action Toolbar in the Doppler Acquisition Mode is similar to that in the 2D acquisition mode.

Note that the advanced snapshot feature is not available in Doppler Acquisition Mode.

3.2.2.2 Scan Pattern

The Scan Pattern parameters used in Doppler Acquisition Mode are identical to the scan patterns in 2D acquisition. See the section Scan-Pattern for further information.

3.2.2.3 Averaging

The first Averaging option in Doppler acquisition is spectrum averaging. It can be used to increase the signal-to-noise ratio while decreasing the imaging speed. Hence, spectrum averaging can simulate an increased acquisition time and in turn change the effective A-Scan rate f.

There are two additional averaging parameters in Doppler Acquisition Mode. They specify how many A-Scans are used to compute phase differences and intensity mean values (lateral), and how many data-points in each A-Scan are averaged to reduce the influence of phase and intensity noise (axial).

By selecting oversampling, the data acquisition will compute a suitable phase value for each acquired pixel by using the neighboring pixel values. If no suitable neighboring values exist (at the edges of the sampled data), no value will be computed. Without oversampling, only every nth pixel is evaluated, where n is determined by the lateral or axial averaging.

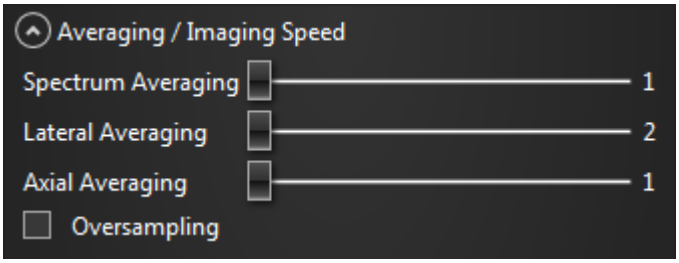


Figure 60 Doppler Averaging Parameters

3.2.2.4 Doppler Angle

If the incidence angle in the fluid is given, it is possible to estimate the velocity of the fluid.

In order to do that, check the check box Show Velocity. Activating the check box enables the estimation of velocities instead of phase differences. The Doppler Angle should be entered.

Figure 61 Show Velocity Check Box, Doppler Angle

Once the check box is active, it is possible to enter the value of the angle between the axial direction and the direction of the flow, in sexagesimal degrees, as depicted in the figure below.

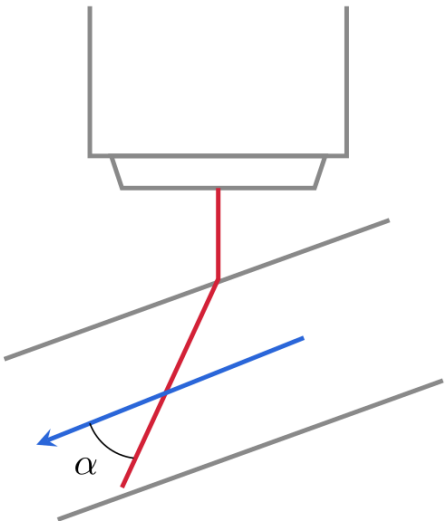


Figure 62 Value of the Angle between the Axial Direction and the Direction of the Flow

The Doppler Angle is the angle between the axial direction in the liquid and the direction of the flow.

Note that, due to refraction, the Doppler Angle is not the angle observed from outside. To estimate the Doppler angle the Snell relation and the refraction index can be used (ThorImage®OCT cannot do that because the software does not know the geometry of the current experiment). The velocity values obtained depend on the refractive index.

3.2.2.5 Recording

The Recording options for Doppler Acquisition Mode are the same as in 2D acquisition, with the exception of the phase data being recorded in addition to the intensity data. See the section Recording for further information.

3.2.2.6 Display Toolbar

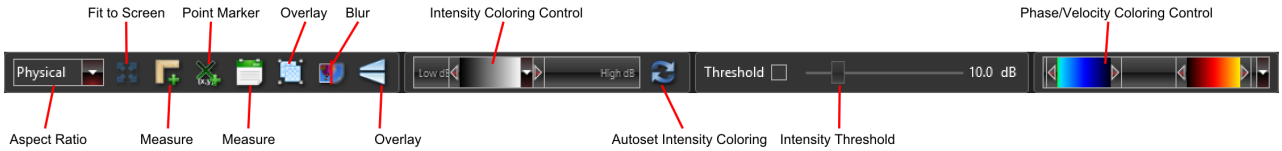


Figure 63 Display Toolbar Settings for Doppler Display

The following controls are the same as shown in 2D acquisition and are described there:

- Aspect Ratio
- Fit to Screen
- Frame Selection
- Coloring Control

Doppler acquisition mode specific display parameters are described below.

Overlay
Intensity image and phase/velocity image are overlaid in a single view. Phase/Velocity images are alpha blended onto the intensity images, but only if a certain intensity threshold is exceeded.

Blur
Intensity and phase/velocity images are blurred to reduce effects of noise.

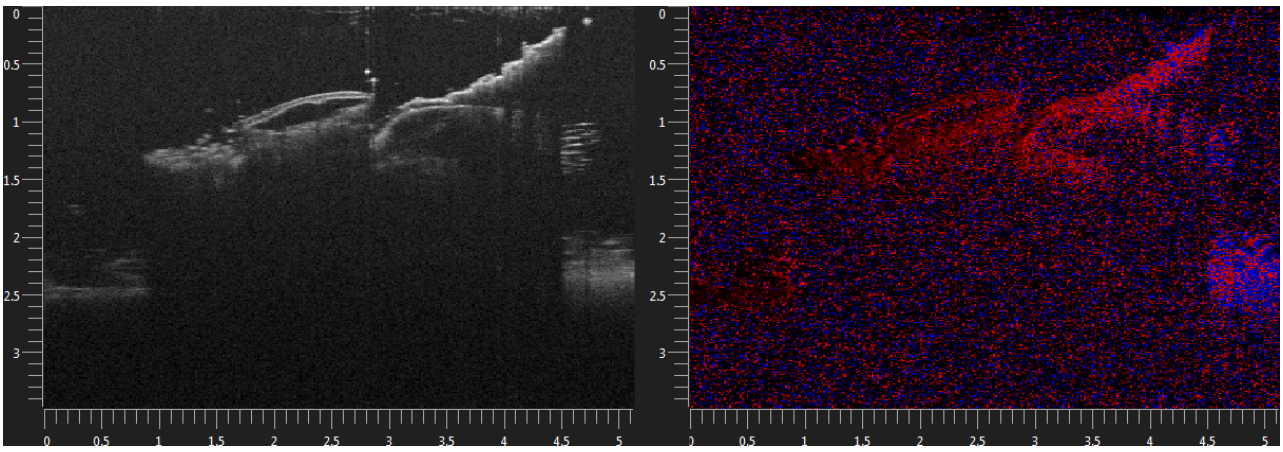


Figure 64 (Left) Doppler Display with Overlay Switched Off (Intensity Image)
Figure 65 (Right) Doppler Display with Overlay Switched Off (Velocity Image)

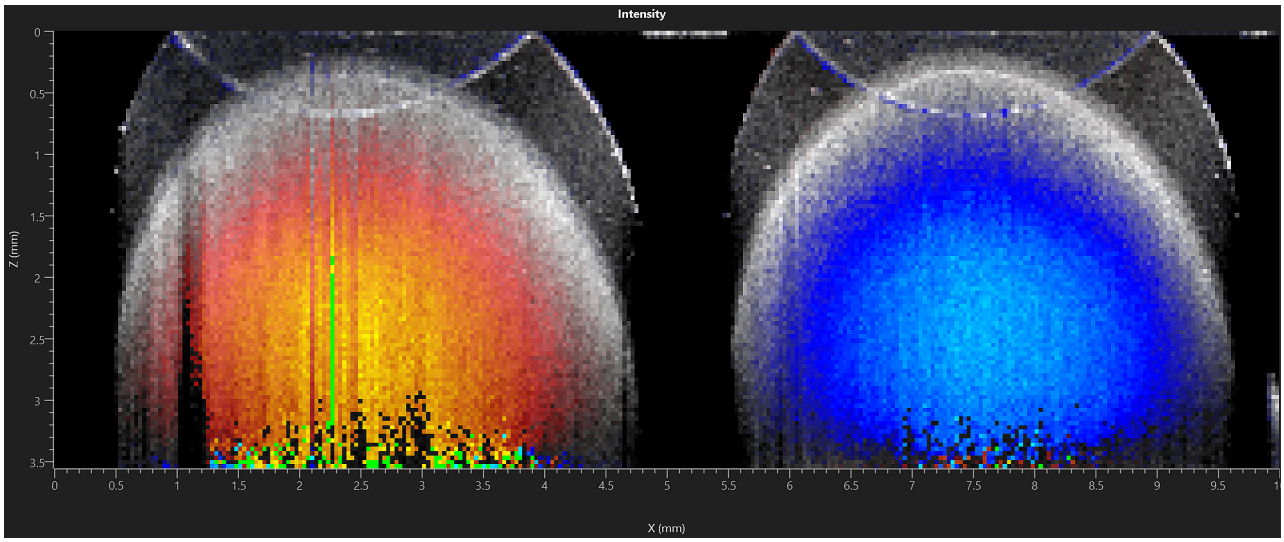


Figure 66 Doppler Image with Overlay Switched On (Phase/Velocity Information is Blended Onto the Intensity Image)

Intensity Threshold

The intensity threshold specifies the minimum intensity for each data point to display data in the phase/velocity image. The intensity threshold option is available for overlay and separated intensity/phase images.

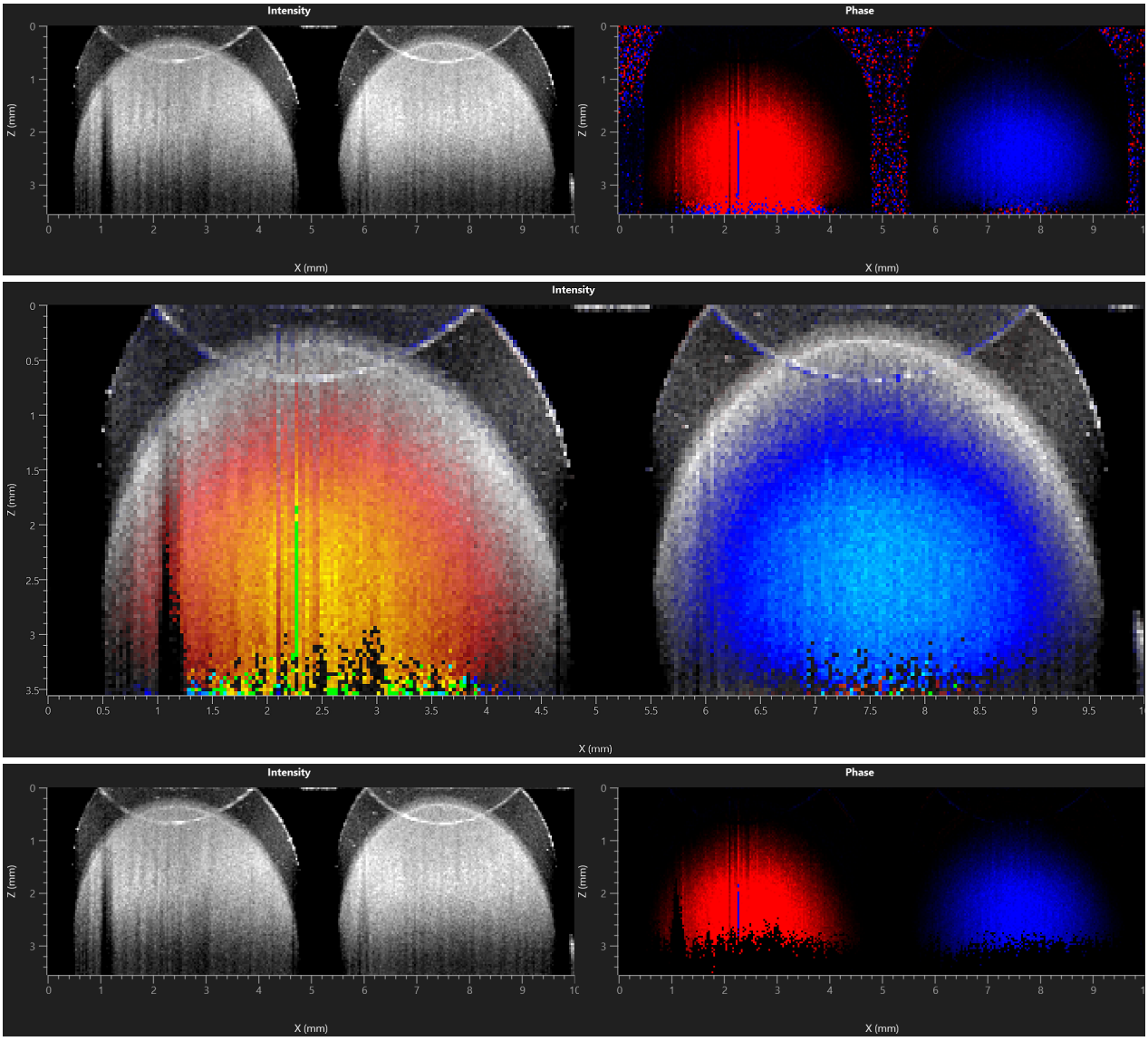


Figure 67 (Top) Intensity Threshold is Set Too Low, Velocity Overshadows Intensity Information Entirely
Figure 68 (Middle) Intensity Threshold is Set Correctly, Phase/Velocity and Intensity Information is Visible
Figure 69 (Bottom) Intensity Threshold is Set Too High, no Phase/Velocity Information is Visible

Phase/Velocity Coloring Control

Specifies which phases/velocity values are colored and determines contrast of the doppler information. The phase regions specified by the control will be colored.

3.2.3 Speckle Variance Contrast Mode

Speckle Variance Contrast Mode can be used for angiographic imaging. It visualizes blood vessels without requiring significant blood flow and without requiring a specific acquisition speed window.

Note that for optimal image quality, the sample has to be stabilized. Furthermore, a gel should be used for matching the refracting index at the sample interface.

3.2.3.1 Action Toolbar

In the Speckle variance mode, the Action Toolbar looks as follows:

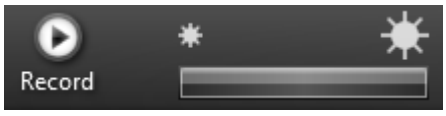


Figure 70 Action Toolbar of the Speckle Variance Acquisition Mode

Record
The *Record* button starts to acquire a single volume with the scan pattern and resolution provided. This is used for single shot acquisition with high sampling rate.

3.2.3.2 Scan Pattern

The Scan Pattern parameters used in speckle mode are identical to the scan patterns in volume mode. See the section Scan Pattern for further information.

3.2.3.3 Speckle Averaging

Speckle Averaging parameters indicate how many successive A-Scans (*Averaging Fast Axis*) and/or B-Scans (*Averaging Slow Axis*) are to be used when computing variance and mean values. Larger values make for better signals but will require more acquisition time and are also more sensitive to bulk motion artifacts.

Figure 71 Averaging Parameters in Speckle Variance Imaging

3.2.3.4 Display Toolbar

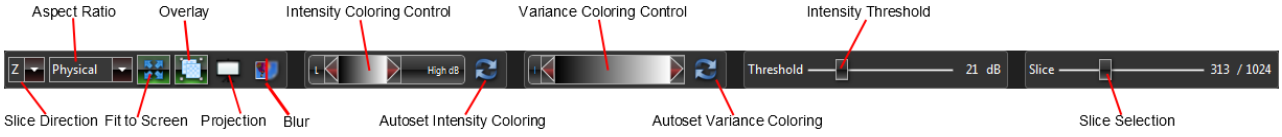


Figure 72 Display Toolbar Settings for the Speckle Variance Display

The parameters Slice Direction, Aspect Ratio, Fit to Screen, Intensity Coloring Control, Autoset Intensity Coloring, and Slice Selection are identical to that in the 3D Slice Display.

Overlay
Mean intensity image and variance image are overlaid in a single view. Variance images are alpha blended onto the intensity images, but only if a certain intensity threshold is exceeded.

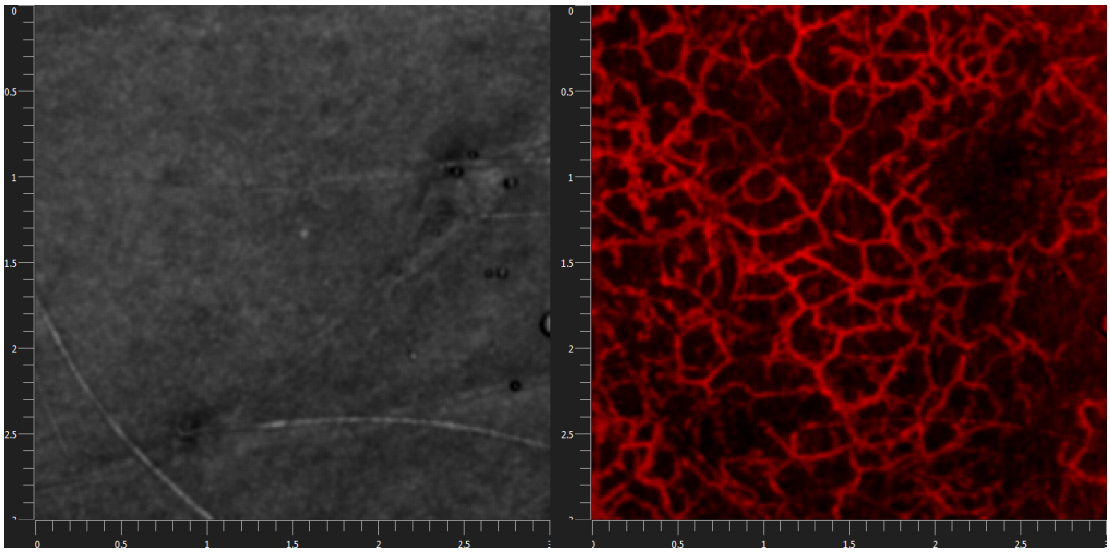


Figure 73 (Left) ***Default Speckle View, Mean Intensity Projection Image***
Figure 74 (Right) ***Default Speckle View,Speckle Variance Projection Image***

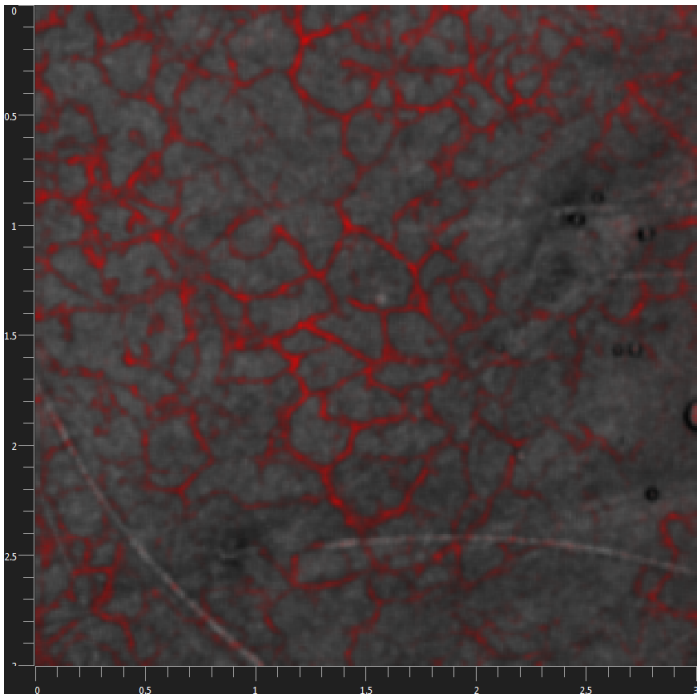


Figure 75 ***Overlay Image of Mean Intensity and Speckle Variance***

Projection

Projection performs a maximum intensity projection (MIP) along the selected axis of the OCT data. Especially in en face display, angiographic images show improved imaging quality when this option is enabled.

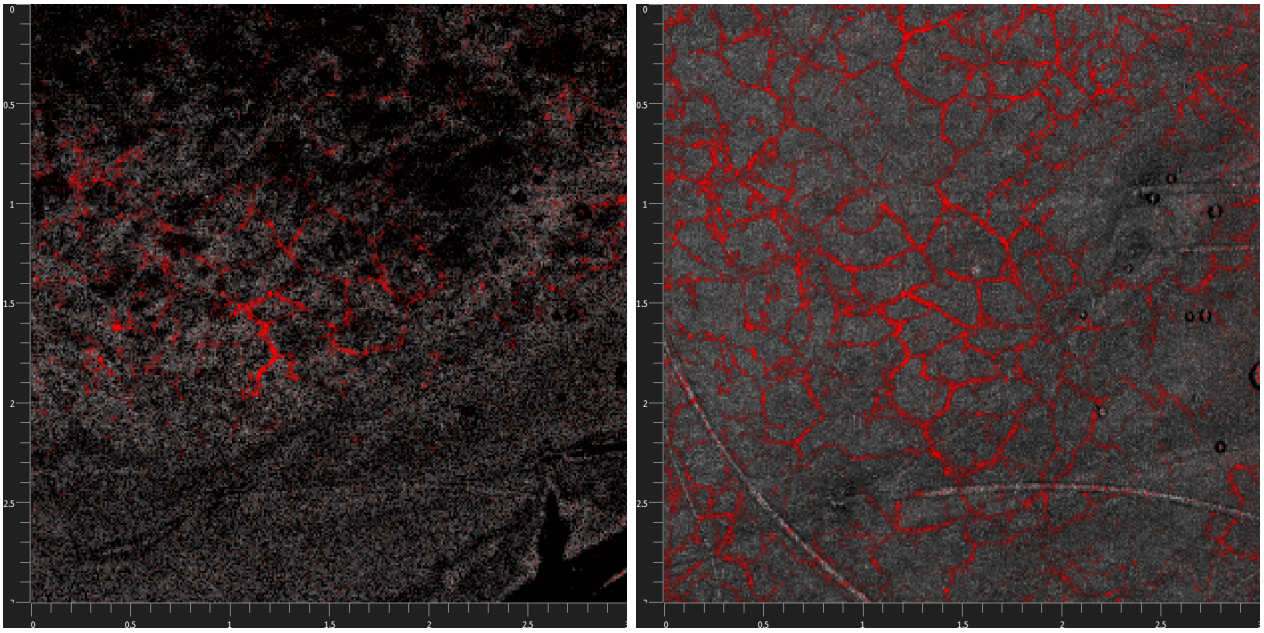


Figure 76 (Left) ***Mean Intensity and Speckle Variance Overlay with no Projection***
Figure 77 (Right) ***Mean Intensity and Speckle Variance Overlay Image with Projection***

Blur

Intensity and variance images are blurred to reduce effects of noise when using the *Blur* button.

Variance Coloring Control

Specifies how variance values are colored and determines contrast and brightness of the angiographic information. The colormap can be changed by right clicking on the middle thumb of the coloring control, which causes a colormap popup to appear.

Intensity Threshold

The intensity threshold specifies the minimum intensity for each data point to overlay data with the speckle variance image. Variance samples where the intensity is below the selected threshold will not be shown in the overlay or the stand-alone variance image.

3.2.4 Polarization-Sensitive Modes

Here we introduce the vocabulary of polarization-sensitive OCT (PS-OCT). We try to keep the explanations at a basic level, but we also want to be precise, as different authors tend to use the same words with different meaning.

Polarization is a property of transverse waves, that is, waves in which the oscillations are transverse to the direction of propagation. Light, an electromagnetic wave, is an example of a transverse wave. Describing polarization amounts to describing the geometry of the oscillations in a transverse plane. This geometrical description on the transverse plane distinguishes two perpendicular axes (reference coordinate system), which can be arbitrarily selected. If the geometry is a line, we speak of linearly-polarized light, and we characterize it with an angle in the reference system. If the geometry is a circle, we speak of circularly-polarized light, and we characterize it by specifying if it circles in .in a left-hand (clockwise) or right-hand

(counter-clockwise) fashion. The most general case is a superposition of linearly- and circularly-polarized light-components, which is generally referred to as elliptical polarization.

In order to build intuition, we consider here the typical case of an OCT measurement, in which light shines on a sample and is reflected at different depths. Some of the incident light penetrates into the sample. At each point in the sample with a change in material properties (interface), part of the penetrating light is reflected. The part that does not get reflected either propagates further (transmission) or gets absorbed (attenuation). The nature of the sample may have the effect that both the propagation and the attenuation depend on the polarization state of the incident light. An anisotropic sample may change the state of polarization of the incident light, and when we measure that change, we can better characterize the sample.

PS-OCT measures the additional information of the polarization state in the interference patterns, and estimates the polarizing properties of the sample. Hence, PS-OCT reveals the sample's anisotropy that modifies the polarization state of light as it travels through it. Under certain circumstances it is possible to deduce that the light gets depolarized as it travels further deep into the sample.

A sample that changes the polarization state of light will do so in both directions of propagation: when the light penetrates the sample up to a point of reflection, and also after the reflection, on its backward run up to the surface of the sample. Hence, the change in polarization that arrives at the detector is the cumulative change of the round trip of the light inside the sample.

Note that a reflection measurement is insensitive to optical activity (when propagation of right- and left-circularly polarized light is different). The reason is that if light travels into the sample forwards and backwards along the same geometrical path, rotational effects introduced on the forward run, get reverted on the backward run. The cumulative effect is thus zero.

Coordinates of Polarization States

This section is useful for the reader who needs to understand the mathematical expressions in the sections below, or who will code their own processing routines. The material here is not needed to understand the physical concepts in the next sections.

The PS-OCT instrument collects two spectra per measurement, corresponding to two orthogonal linearly-polarized states. We refer to them as Camera 0 (which reads the 0° linear polarized light) and Camera 1 (which reads the 90° linear polarized light).

The setup of the PS-OCT instrument has been tuned to produce the following experimental results:

- If the sample is a mirror at the focal plane of the objective, most of the measured signal will be collected by Camera 0. Some of the light is also collected by Camera 1 because the optical components depart from their ideal behavior. This is something that can be checked by the user (just tilt the mirror slightly if saturation is an issue).
- If the scanner unit did not have any quarter-wave plates, the result would be the opposite: almost all of the light would be collected by Camera 1, and only a residual part by Camera 0. It is absolutely not recommended to try testing this condition, because it necessitates disassembling the scanner unit.

The signals of both cameras are processed independently, following exactly the same procedure as if each one of them were a standard OCT spectrum. However, instead of computing the standard A-Scan signal expressed in decibels, the complex reflectances r_0 and r_1 are computed as a function of depth. The individual intensities get computed directly from the complex reflectances as:

$$I_0 = r_0 \cdot r_0^* \qquad\qquad I_1 = r_1 \cdot r_1^*$$

For reference: the decibel-intensity usually displayed in OCT pictures is ten times the logarithm of the intensity.

The total intensity is the addition of the intensities:

$$I = I_0 + I_1$$

Due to the conservation of energy, the expressions above are valid in both k and z spaces. However, these sections aim to explain the meaning of the images that the user obtains using the software. Therefore, it is assumed that each quantity is a function of the coordinates of the computed pixel (x, y, z).

Retardation and Optic Axis (Anisotropy)

If the nature of the sample modifies the polarization state of incident light, then the sample has a way to distinguish electromagnetic oscillations depending on their dynamics. In other words, it is not isotropic, in the sense that different polarization states get affected differently. This property of a sample is called anisotropy.

The sample's anisotropy may modify the polarization state of incident light as it propagates through it. Two common scenarios are that a given polarization state gets particularly attenuated, or that the propagation speed of certain states is slower (more retarded) than others. The first situation is commonly named dichroism, the latter birefringence:

- **Dichroism**
  Unequal attenuation of differently polarized light.
- **Birefringence**
  Unequal propagation speed of differently polarized light.

A commonplace example of dichroism is sunglasses that block linear polarized light in one direction.

Sources of Birefringence

- Combination of materials with different dielectric constants in oriented geometries. This is known as "shape anisotropy". Examples in this category are filamentary extra-cellular structures (e.g. collagen fibers) or even sub-cellular structures (e.g. microtubules). Man-made materials may also exhibit shape anisotropy if the fabrication procedures lead to (partial) alignment of microscopic linear structures, with or without internal stresses. These structures are much smaller than the typical OCT wavelengths, hence they cannot give a localized reflection in the usual concentrations, but PS-OCT may still be sensitive to the induced change in polarization. A general theory of the underlying effect was first given by O. Wiener in 1912, and a more readable one by R. Oldenbourg and T. Ruiz (1989).
- Crystalline materials may exhibit "inherent anisotropy" if their crystalline structure is non cubic. A prominent example is the naturally occurring mineral hydroxylapatite (e.g. in teeth).
- A combination of the two above (shape and inherent anisotropies) is also possible. For example, when an inherently birefringent matrix is porous and the filling material is non birefringent. H. M. Theuns et al. (1993) describe a situation in this category, found in biological samples.

The sample anisotropy is usually interpreted as pure birefringence (for most biological samples dichroism is negligible) and displayed in terms of retardation and optic axis. The next section gives an overview of the computations. For a detailed explanation of the computations from measured data refer to the review paper by J. de Boer and T. Milner (2002).

A purely birefringent material behaves as a retarder, as we explain next. Recall that polarization is a property of transverse waves, that is, a geometrical description of the oscillations in the transverse plane. Hence it is possible to use a coordinate system with two perpendicular axes, which can be arbitrarily selected. In a birefringent sample, a particular linear-polarization state propagates slower than the one perpendicular to it. In other words, it is affected by a retardation. Accordingly, we speak of a fast axis and

of a slow axis which are characteristic of the sample. If the sample is not uniform, the fast and low axes will not be the same at all material points inside the sample.

Outline of the Computations

In this section we give a brief overview of the computations. Regardless of previous knowledge (e.g. J. de Boer and T. Milner (2002)), this section may be useful in understanding the way individual A-Scans are obtained, which is important for writing custom signal processing routines.

The instrument collects two spectra per measurement, corresponding to two orthogonal linearly-polarized states. We refer to them as Camera 0 and Camera 1 raw signals (because in both cases a line camera reads out the spectra).

In a given system, the dispersion is not identical for all polarization modes. The parameter *j* in the processing algorithm can be adjusted to compensate this effect.

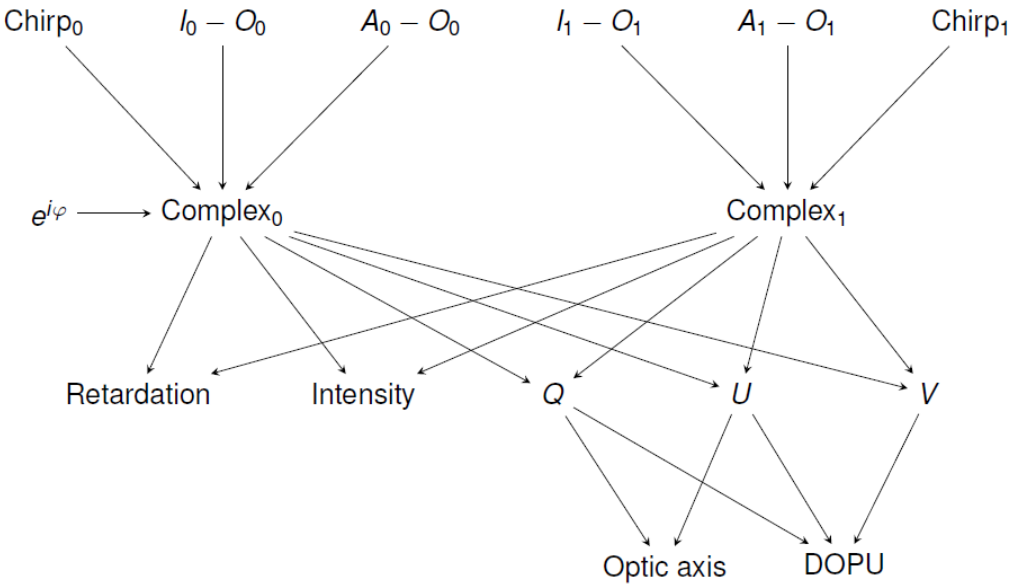


Figure 78 Stokes Parameter Dependency Tree

Each spectrum is treated separately to obtain the complex reflectivity of the sample as a function of the depth. That is, for each camera the intensity $I_{0/1}$ measured with the probe in focus, the offset $O_{0/1}$ measured with light source turned off, the intensity $A_{0/1}$ measured without sample, and the lambda to k function ($Chirp_{0/1}$) are combined to obtain a complex A-Scan (its module, expressed in dB, would be the real-valued A-Scan usually displayed in standard OCT instruments).

Retardation

Retardation is the difference in optical path inside the sample for two orthogonal linearly-polarized states. As explained by J. de Boer and T. Milner (2002), in PS-OCT it is the angle that defines the proportion between the irradiances measured in each polarization state. Both are positive quantities, so the angle necessarily lies in the first quadrant, in the interval $[0, +\pi/2]$ ($[0,90°]$).

In mathematical terms:

$$Retardation = \tan^{-1}\left(\sqrt{I_0/I_1}\right) \in [0, +\pi/2]$$

Because the measured change in polarization is the cumulative change that light undergoes inside the sample, retardation pictures require interpretation. The retardation can be made more intuitive by considering what happens in an ideal sample, as follows: If the sample had uniform birefringence (i.e. the birefringence is the same at all material points of the sample), the computed retardation would increase

uniformly (because of the cumulative effects already discussed): it should be proportional to the depth. Because the value cannot exceed $\pi/2$ (or $90°$), it is wrapped (instead of growing further beyond $\pi/2$, it decreases towards zero).

Optic Axis

We now consider the plane transverse to the propagation. The reference coordinate system of the instrument (defined by the geometry of the measurement) does not need to be the one of the sample (defined by the fast and slow axes). The relative angle between both can be computed and is called the "optic axis".

The idealized example of the previous section can also be helpful here. If the sample bears uniform birefringence, the optic axis will be proportional to the depth (because of the cumulative effects already discussed). Rotations differing by π (or $180°$) cannot be distinguished, and for this reason this parameter only gets values in the interval $[-\pi/2\ ,+\pi/2]$.

The mathematical expression depends on two Stokes parameters, Q and U, that will be defined in the next section:

$$Optic\ Axis = \frac{1}{2} atan2(U,Q) \in [-\pi/2\ ,+\pi/2]$$

Here *atan2* is the inverse-tangent function computed from two parameters, thus enabling a four-quadrant description.

Stokes Parameters

Most authors describe the polarization state of light through the four Stokes parameters. The first one is the intensity (*I*), which is the sum of all irradiance terms.

Where the three parameters are:

$$I = Q^2 + U^2 + V^2$$

Q: Proportion of Horizontally Polarized Light $(Q = -1)$ or Vertically Polarized Light $(Q = +1)$

$$Q = \frac{I_1 - I_0}{I_1 + I_0}$$

U: Proportion of Light Linearly Polarized at 45° $(U = -1)$ or Linearly Polarized at 135° $(U = +1)$

$$U = \frac{2Re(r_1 \cdot r_0^*)}{I_1 + I_0}$$

V: Proportion of Left-Circularly Polarized Light $(V = -1)$ or Right-Circularly Polarized Light $(V = +1)$

$$V = \frac{-2Im(r_1 \cdot r_0^*)}{I_1 + I_0}$$

With:

Re: Real Proportion

Im: Imaginary Proportion

The Stokes Vectors are normalized such that in the case of fully polarized light the equality

$$Q^2 + U^2 + V^2 = 1$$

holds and the parameters Q, U and V lie in the range $[-1, +1]$.

OCT is a technique that measures interference patterns. As such, it can only measure light components that are polarized, and it is insensitive to depolarization effects. Therefore, the equation

$$Q^2 + U^2 + V^2 = 1$$

holds at every pixel. The Stokes parameters are also useful to describe situations in which

$$Q^2 + U^2 + V^2 < 1$$

(partially polarized light), but this will not be discussed here, as this is not relevant to the OCT techniques described in this manual.

Degree of Polarization Uniformity (DOPU)

PS-OCT cannot measure the degree of polarization, because unpolarized light does not produce interference patterns and thus cannot be measured by OCT.

However, in some regions inside samples it can be observed that the values of the Stokes parameters vary between neighboring pixels in a random fashion, and no Stokes parameter is prevalent (unlike the incident light). The usual interpretation is that that region of the sample deletes the polarization information, or more simply stated, it depolarizes the incident light.

This effect can be quantified by adding the squares of the averages across pixel-neighborhoods:

$$DOPU = \sqrt{\langle Q \rangle^2 + \langle U \rangle^2 + \langle V \rangle^2} \in [0,1]$$

This parameter is called the Degree of Polarization Uniformity (DOPU), in the interval $[0, +1]$. It is zero if all the Stokes parameters average to zero (complete depolarization), and it is one if the Stokes parameters are uniform in the pixel-neighborhood considered. The amount of averaged pixels can be selected in ThorImage®OCT.

3.2.4.1 2D Polarization-Sensitve Mode

3.2.4.1.1 Action Toolbar

In the 2D Polarization-Sensitive Mode, the Action Toolbar looks as follows.

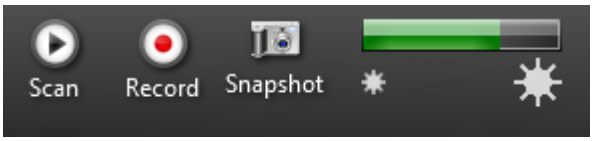


Figure 79 Action Toolbar Options in 2D Polarization-Sensitive Mode

Scan

Using the *Scan* button starts and stops 2D OCT data acquisition.

Record

The *Record* button can be used to acquire a consecutive stack of many B-Scans, acquired as quickly as possible after each other. The acquired stack of B-Scans is shown as a single entry in the dataset list. It can be viewed by clicking on the respective entry in the dataset list.

Snapshot

When the OCT Imaging System is acquiring two-dimensional data, a single image can be stored using the *Snapshot* button. The acquired B-Scan appears in the dataset list and can be selected in order to view it.

A snapshot will store enough information to allow the re-computation of all PS parameters at a later time, independently of what is on display. If the B-Scan signals of the individual cameras should also be retrievable later on, then make sure to select *Store Spectral Raw Data* or *Store Spectral and Processed Data* in the Dataset and Export Options in Settings Dialog.

3.2.4.1.2 Scan Pattern

The scan pattern options and functionality are the same as in standard 2D acquisition. Please see the section Scan Pattern in the user guide for more information.

3.2.4.1.3 Display Toolbar

The Display Toolbar provides control over the settings affecting the way in which 2D polarization-sensitive OCT data are viewed. It contains various options to change the aspect ratio of the display, perform length measurements of structures in the B-Scans, overlay them, blur, or flip. Additionally, the Display Toolbar provides controls to select the desired parameters and to adjust the coloring parameters. In the case of a multiframe dataset, the frame number can be freely chosen. And in the case of DOPU, the averaging algorithm and the geometrical extensions can be selected.

A full-blown polarization Display Toolbar contains the following elements.

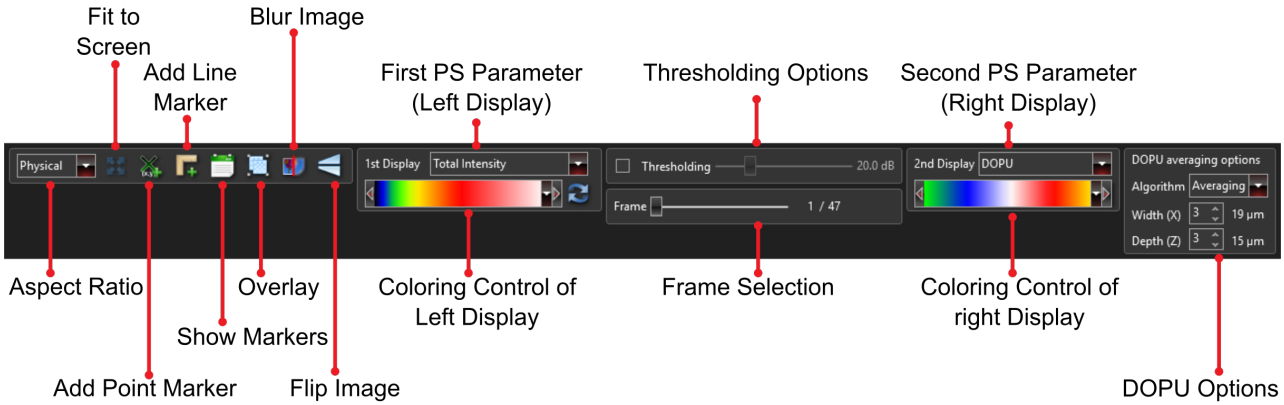


Figure 80 Display Toolbar Settings for the 2D Polarization-Sensitive Display

Display Toolbar parameters specific to 2D polarization-sensitve mode are described below. All other controls are identical to the controls in the 2D Display Toolbar.

Overlay

Overlays are meant to condense the information of two pictures into a single one. Usually a gray scale is selected for one of the two pictures, such that the polarization-sensitive areas appear brighter, and the not so interesting areas darker. The other display is configured to use a color scale, in which the color contrast enhances the desired features. Then, the blend of both pictures combines the two meanings together.

Blur Image

Blurring the images is equivalent to applying a Gaussian filter on them, thus generating new pictures that look smoother. This filter has two consequences that must be weighted to decide its application:

- Attenuation of noise.
- Loss of detail: details whose scale is too small get smoothed away.

Parameter Selection

The birefringent or depolarizing effect of a sample can be revealed by displaying different parameters that describe the polarization state of the light returning to the detectors.

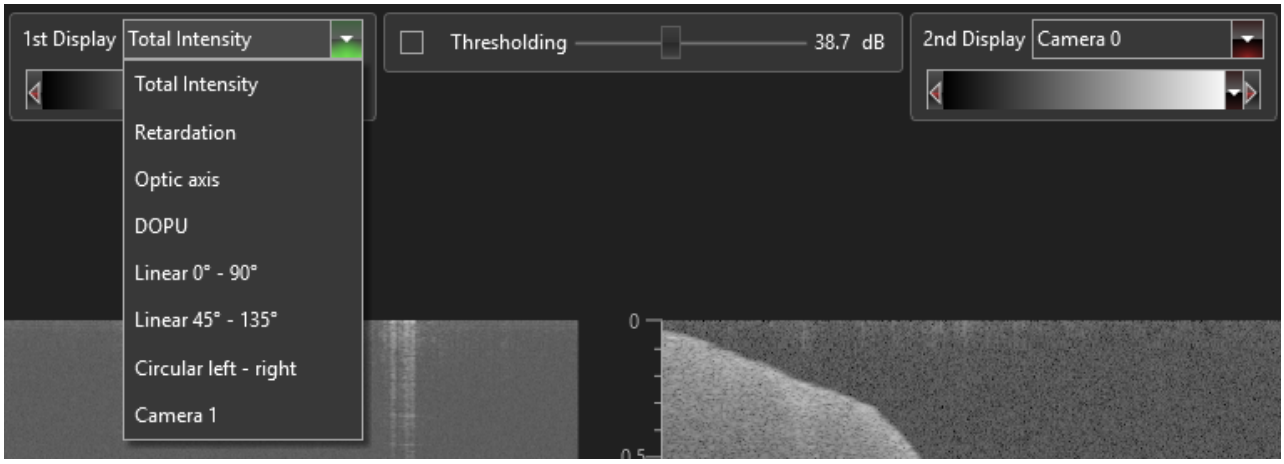


Figure 81 Selection of PS Parameters on Display

Possible Parameters:

- Total Intensity (the Sum of the Intensities of Both Sensors)
- Retardation and Optic Axis (Anisotropy)
- Degree of Polarization Uniformity (DOPU)
- Linear 0° - 90° Polarization State (Stokes Parameter Q)
- Linear 45 - 135 Polarization State (Stokes Parameter U)
- Left- or Rght-Circular Polarization State (Stokes Parameter V)
- Camera 0 (Just the Intensity, as if it were a Standard 2D Measurement)
- Camera 1 (Just the Intensity, as if it were a Standard 2D Measurement)

The combo-boxes do not allow selecting the same parameter at both sides.

The computation of the different parameters is very CPU intensive. For that reason, only the parameters that are displayed get calculated.

Color Scales Options

The Color Scales Options are meant to enhance the contrast at places of interest.

The coloring control specifies the dynamic range and the color map that is used for creating false color images. By adjusting the position of the left and right *Slider* button ( ), the dynamic range can be increased or decreased. As the distance between the buttons increases, the contrast of the images decreases. By moving the entire slider, the brightness of the images can be controlled.

Right-clicking the *Coloring Control* brings up a popup-menu where the desired color map can be selected.

DOPU Averaging Options

As stated above, the degree of polarization uniformity is computed as an average in the geometrical neighborhood of each pixel. Two details of that computation can be selected:

- The specific algorithm: use a standard Averaging, a Median, or a convolution with a Gaussian (the closest pixels are weighted heavier in the average than more distant ones).
- The geometrical extent of the averaging: The user can select the number of pixels involved (always an odd number, the computed pixel is the one in the middle), but the system computes and shows the equivalent physical size.

For the sake of image refresh rate we recommend displaying a different PS parameter when setting up the focus distance or the amount of illumination. It should be kept in mind that the DOPU computation

involves quite an amount of CPU work, in particular if the image dimensions are on the order of a thousand pixels.

Thresholding

Thresholding can be used to omit those pixels for which the total intensity value is lower than the selected value (expressed in dB). The omitted pixels are drawn in background color. The intention is to leave out those portions of the image with a very low photon count, which usually translates into a poor signal-to-noise ratio.

Spatial Averaging

Spatial Averaging substitutes each pixel with an average of itself and its neighborhood. Note that large averaging area imply long computation times.

Note that the spatial averaging does not affect DOPU (dregree of polarization uniformity), because DOPU itself entails a spatial averaging (with its own set of parameters).

3.2.4.2 3D Polarization-Sensitive Mode

The concepts behind a 3D Polarization-Sensitive Mode measurements are exactly the same as in the two-dimensional case. Please see the section 2D Polarization-Sensitve Mode for more information.

3.2.4.2.1 Action Toolbar

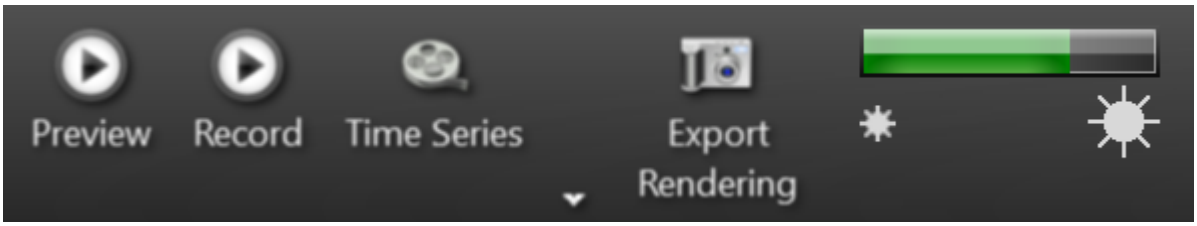


Figure 82 Action Toolbar Options in 3D Acquisition

Preview

The 3D Acquisition provides a *Preview* button that can be used to rapidly acquire 3D volumes at a very fast rate. Even if only one volume is shown, the system keeps track of all the information needed to compute any other PS parameter. In this mode, multiple volumes are acquired and visualized online in the 3D display until the acquisition is stopped by the user. The data that is acquired using the preview mode is not stored on disk. Use the *Record* button to create high quality OCT images of the examined samples.

The size of the preview dataset is defined in the preview group of the Dataset Parameters control. This size will generally be significantly lower than the actual volume acquisition size applied when using the *Record* button.

Record

The *Record* button can be used to acquire a single volume with the scan pattern and resolution specified in the dataset parameters. It is used for single shot acquisition. This operation will acquire and store enough information to be able to compute all PS parameters at a later point in time. If it is desired that the signals of the individual cameras are retrievable later on, then be sure to select *Store Spectral Raw Data* or *Store Spectral and Processed Data* in the Dataset and Export settings window.

During the scan, a progress bar with a *Cancel* button is shown. The current acquisition can be stopped by pressing the *Cancel* button.

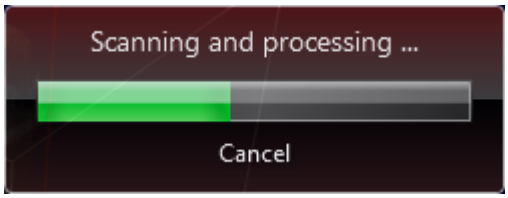


Figure 83 Scan Progress and Cancel Button

Time Series

Using the *Time Series* button, one can invoke a series of 3D measurements. In the drop-down list of the button one can adjust the number of volumes to be acquired and the scan pause between successive volumes. Note that for each measured volume, a new 3D dataset is created.

The minimum available scan pause time is limited by the time calculated for a single scan/storage process.

Export Rendering

Using the *Export Rendering* button, one can export the currently displayed volume rendering as a single image, much like a screenshot of the display area.

If the selected probe is configured to skip automatic calibration measurements, the toolbar will provide buttons for calibration of the apodization spectrum. There are two options: the actual scan can be used as calibration, or a manual calibration can be acquired. Please note that the manual calibration cannot be performed during an acquisition.

Figure 84 Alternative Options for Calibration

3.2.4.2.2 Scan Pattern

The Scan Pattern options and functionality are the same as in standard 3D acquisition. Please refer the section Scan Pattern in the user guide for more information.

3.2.4.2.3 Display

The display functionality of 3D polarization-sensitive measurements is an extension of the 3D display functionality. The parameter on display can be selected with the controls on the bottom left corner.

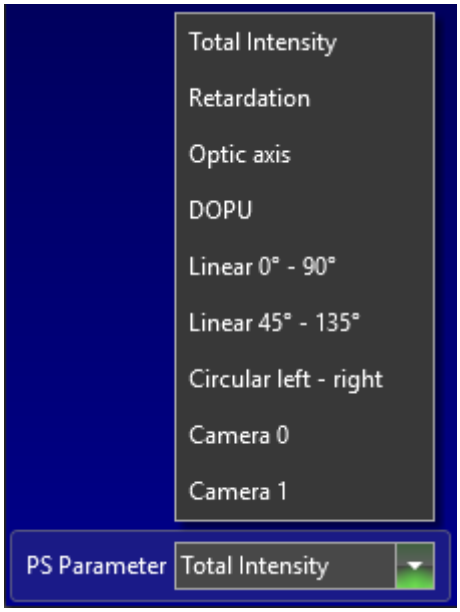


Figure 85 Selection of the Parameter on Display

The possible parameters are:

- Total Intensity (The Sum of the Intensities of Both Sensors)
- Retardation and Optic Axis (Anisotropy)
- Polarization-Sensitive Modes
- Stokes Parameters: Linear 0° - 90° Polarization State (Stokes Parameter Q)
- Stokes Parameters: Linear 45° - 135° Polarization State (Stokes Parameter U)
- Stokes Parameters: Polarization State (Stokes Parameter V)
- Camera 0 (Just the Intensity, as If it Were a Standard 3D Measurement)
- Camera 1 (Just the Intensity, as If it Were a Standard 3D Measurement)

Depending on the selected parameter, more options may appear, as shown in the following picture.

Figure 86 Options Associated to the Parameter on Display

Threshold Options

The threshold options can be used to render transparent those portions in the acquired volume in which the signal to noise ratio of the whole system does not reach a given value. For example, the following procedure may be applied:

- Select Total Intensity as displayed parameter and use the threshold option at the top to find a reasonable range of intensities. Hover the mouse over that threshold control at the top and take note of the minimum value on display, because it is an estimation of the noise level.
- Now select a different parameter (e.g. Retardation). A new threshold control appears on the right of the parameter selection control. Move the slider a few dB above the noise level previously estimated to filter the signals that cannot really be distinguished from noise.

DOPU Averaging Options

The DOPU averaging options and functionality are the same as in PS 2D acquisition. Please refer to the section Polarization-Sensitive Modes in the user guide for more information.

3.2.5 Python Processing Modes

The Python Processing feature allows the user to create their own processing and display it live in ThorImage® OCT. The Python Processing bypasses the default signal processing and enables the user to seamlessly integrate their own signal processing into the workflow provided by ThorImage®OCT environment. This is especially usefull for the development of prototypical signal processing algorithms and for teaching purposes.

How it Works

Python processing bypasses the default processing by redirecting raw data and parameters to a processing method executed in the Python interpreter. A diagram of the data flow comparing default processing and Python processing can be seen in ***Figures 87*** and ***88***, with ***Figure 88*** depicting the temporal workflow. The red dotted boxes in ***Figures 87*** and ***88*** indicate the scope of the ThorImage®OCT. The blue dotted boxes indicate the scope of the Python interpreter. The blue solid boxes in ***Figure 88*** indicate direct communication between the interpreter and ThorImage®OCT.

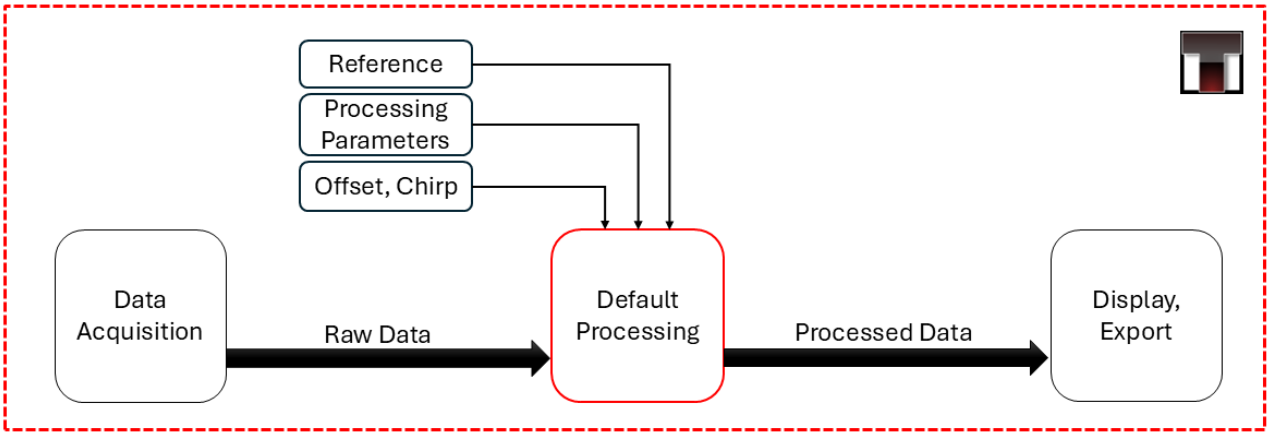


Figure 87 Dataflow of the Default Processing

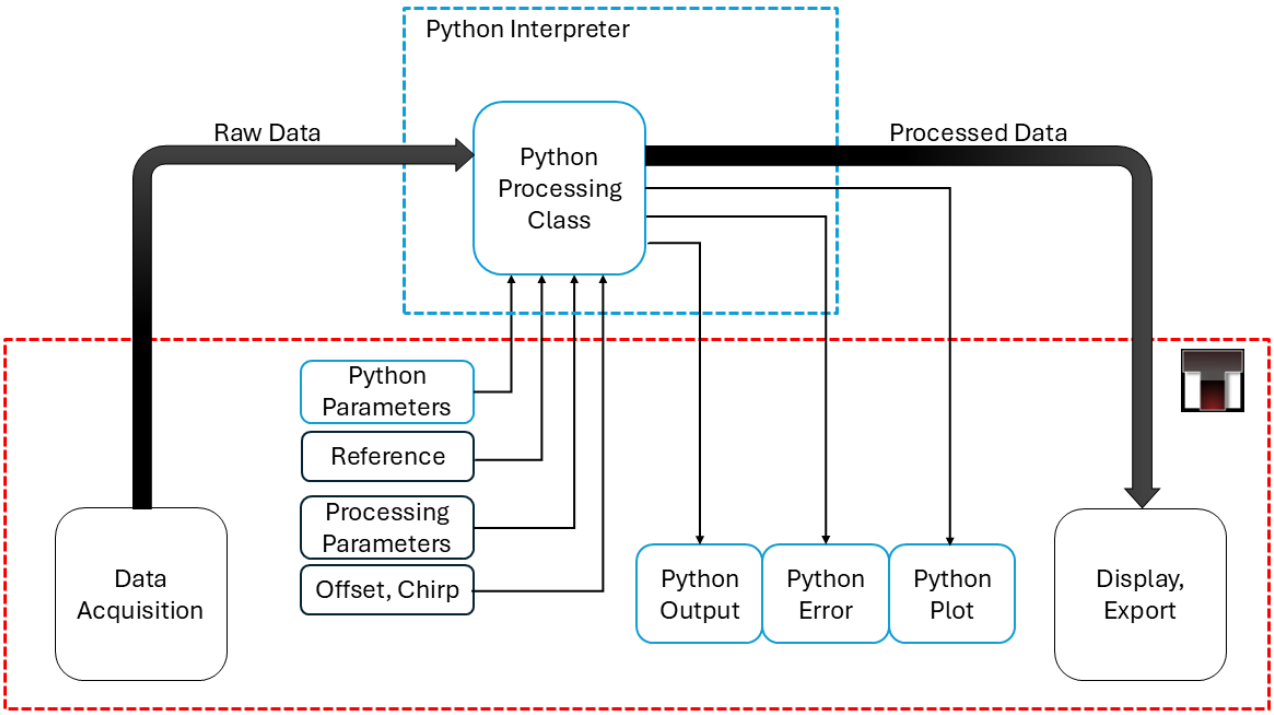


Figure 88 Dataflow when Python Processing is Activated

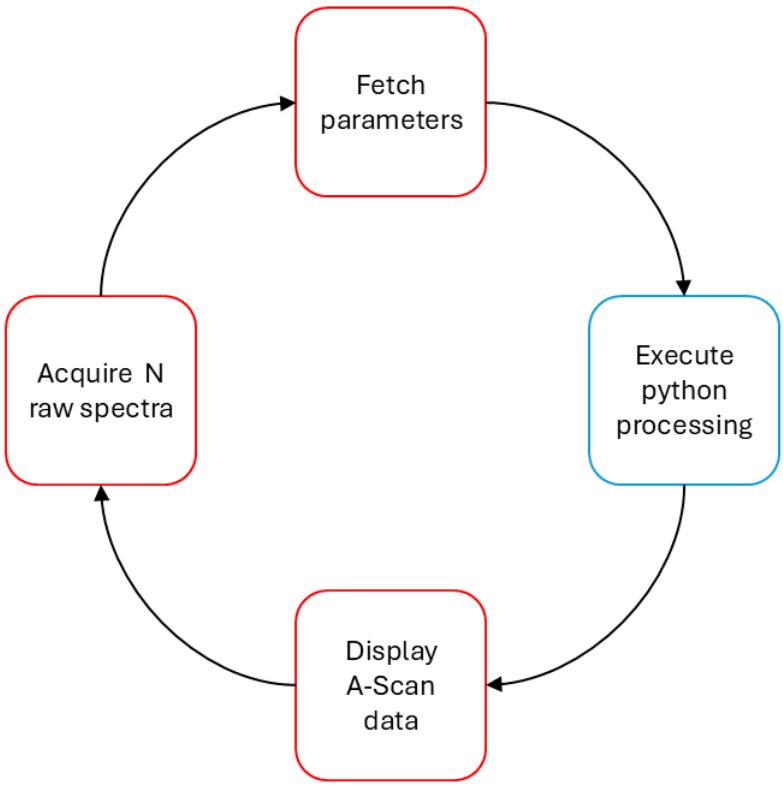


Figure 89 Processing Cycle when Using Python Processing

Upon initialization, the processing class is provided with the offset and chirp vector of the OCT device and a set of specified Python parameters. These variables are accessible within the scope of the class throughout the processing. While the offset and chirp vector are constants, the values of the Python parameters can be changed at any time from within ThorImage®OCT.

Each acquisition cycle starts with the acquisition of N raw spectra. Python's execute method is called with the latest raw data, the reference spectrum, and the processing parameters. The raw data is an array of shape MxN where M represents the number of pixels per spectrum and N represents the number of spectra. The reference spectrum is an array of shape MxJ, where J represents the size of the Apodization window. The processing parameters contain the averaging settings as specified in the imaging mode in ThorImage®OCT, as well as a string identifier indicating the currently active acquisition mode.

Throughout the execution, all console outputs, exceptions, and Matplotlib plots are redirected to the scripting pane in ThorImage®OCT. Please note that the execution of the processing stops in case of an exception.

The execute method should return an array of shape

$$\frac{M}{2} * K$$

where K represents the number of A-Scans after averaging by the factors specified in the processing parameters.

For more details, please find the the examples in the installation directory:

C:\Program Files\Thorlabs\SpectralRadar\Python\ThorImageProcessing\basic_example_processing.py
C:\Program Files\Thorlabs\SpectralRadar\Python\ThorImageProcessing\ext\abstractprocessing.py

Please note that the activation of the Python Processing mode is described in the section Processing.

Python processing offers exceptional flexibility, but there is also the potential for problems. Modifying the code examples provided with the SDK is an ideal place to start. Always ensure data consistency in terms of shape and type. For instance, maintain the output shape of the processing as shown in the basic example. Altering the output shape or data type may cause the application to crash.

3.2.5.1 Limitations

Please note that the Python acquisition brings limitations compared to the default processing.

- Offline Processing of the Data is not Available
- Processing Option Store Spectral Raw Data is not Available
- Doppler Acquisition Mode is not Available yet
- There is no support for Polarization-Sensitive OCT; however, the individual sensors can be used with Python processing.
- No Live Preview in 3D Acquisition

3.2.5.2 Action Toolbar

The Action Toolbar looks similar to the default 2D Aquisition. However, on right side the *Reload Processing* button now appears.

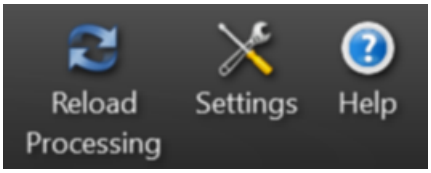


Figure 90 Reload Processing Button

Reload Processing
The implementation of the Python processing can be modified on-the-fly with ThorImage®OCT without restarting the ThorImage®OCT. However, to bring these code changes into action, the processing needs to be reloaded. Clicking the *Reload Processing* button reloads the selected Python file and all user defined

imports. The interpreter itself is not reloaded. Reloading the processing can also help to resolve error states of the Python script.

3.2.5.3 Dataset Parameters

Python Paramters

Python Parameters can be used to parametrize the user's processing live in the ThorImage®OCT. The number and type of parameters have to be specified within the user's referenced Python script.

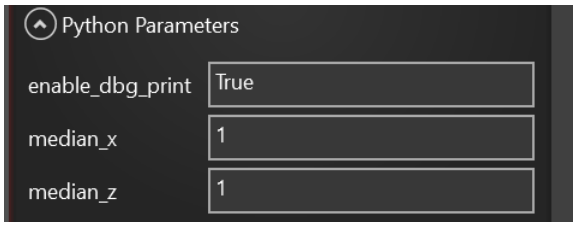


Figure 91 Python Parameters Example

Please see the basic example to check how to specify parameters for the user's processing.

C:\ProgramFiles\Thorlabs\SpectralRadar\Python\ThorImageProcessing\basic_example_processing.py

Averaging

While B-Scan averaging is not available for Python processing, A-Scan Averaging can be controlled by using the corresponding slider in the Dataset Parameters.

Please ensure that the selected averaging is actually applied in user's processing. Otherwise the size of the output data may not be consistent.

Colormaps

In default 2D Acquisition the colorbars have a constant minimum and maximum range. This is feasible because the processing scales the output based on the physical properties of the respective system. However, in Python processing the scaling of the output is not determined. One can change the maximum and minimum values based on their needs. After changing the *Minimum* button click on Autoscale to optimize the colormap within the new boundaries.

Figure 92 Colorbar Range

3.2.5.4 Python 1D Acquisition

The Python 1D acquisition offers similar functions to the standard 1D acquisition, but also offers Python-specific functions, as described in the section Python Processing Modes.

Please note that the minimum and maximum boundary intensity of the A-Scan display can also be changed to fit the output of the user processing.

Figure 93 A-Scan Display Range

3.2.5.5 Python 3D Acquisition

Python 3D Acquisition behaves similar to the default 3D Acquisition while providing similar Python features as the Python 2D Acquisition. However, please note that a live preview is not available in Python mode due to limited performance of the Python processing.

3.2.5.6 Scripting Console

The scripting pane displays the running Python interpreter. The pane has three tabs.

Errors

The Error tab becomes selectable whenever a Python exception occurs. The implementation can be modified. With pressing the *Reload* button code errors will be systematically resolved without restarting the application.

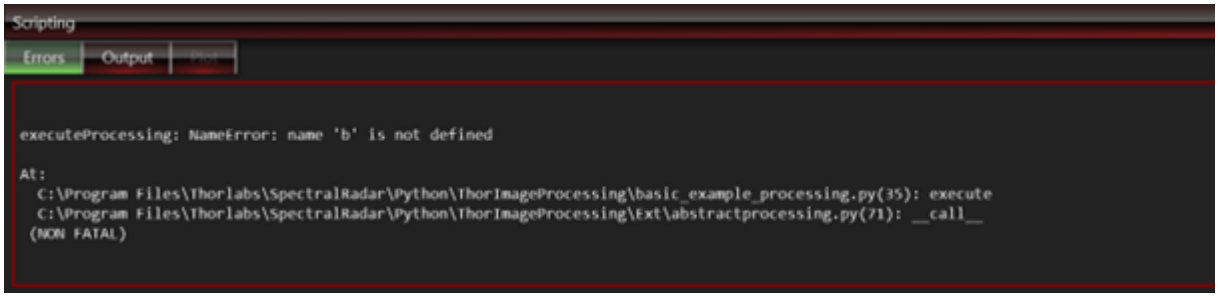


Figure 94 Scripting Pane Errors

Output

In the Output tab, the redirection of Python's console output is shown. For example, the output of the print function will be shown here. This output can be used to print the shape of matrices to verify data consistency throughout development. However, use it with caution regarding execution time, as it might slow down the acquisition and processing loop. The *Clear* button on the left clears the console output.

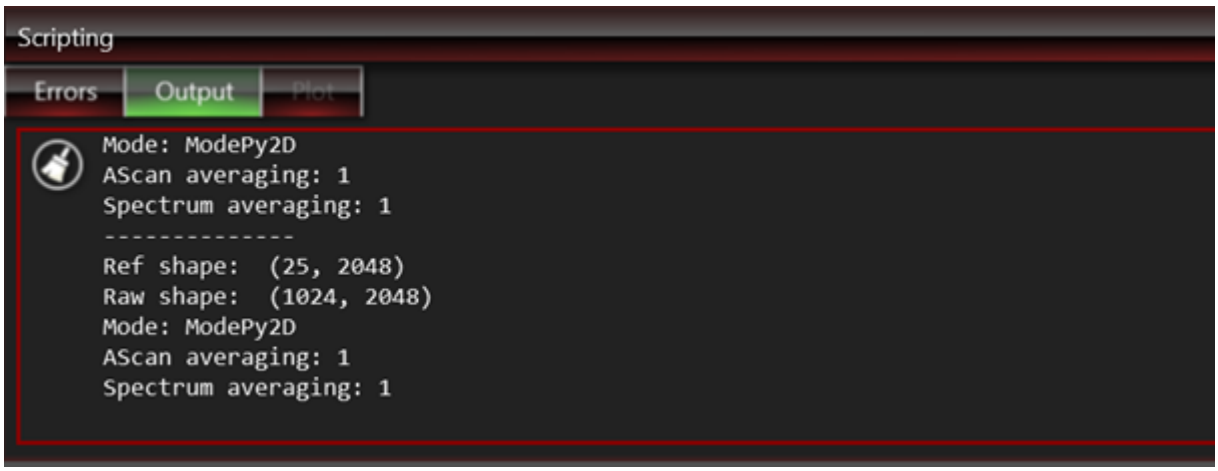


Figure 95 Scripting Pane Output

Plot

The Plot tab contains a list of figures plotted with matplotlib. The ThorImage®OCT includes a matplotlib backend that redirects all matplotlib plot handles to the scripting pane. This function can be used to to visualize different processing steps, either for educational purposes or to ensure data consistency. Pressing the *Clear* button on the left will clear all plots currently shown in this window.

3.3 Action Toolbar

The Action Toolbar provides controls to perform actions in the current acquisition mode. Data acquisition can be started and stopped from here using the *Scan/Stop* button. Single snapshots or entire scans can be captured by clicking the *Record* button. The bar with the two sun symbols displays the current reference intensity if applicable to the OCT system.

When viewing datasets, the Action Toolbar will display options for opening the dataset in ImageJ (if installed) or exporting the data to various export formats.

3.3.1 Reference Intensity (SD-OCT Only)

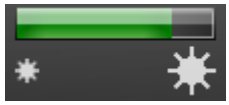
The reference intensity shows the amount of light from the reference arm that is reaching the detector.

For optimal image quality, ensure that the reference intensity is within the green range (as shown in the lower left example).

No Reference Light

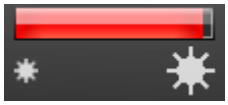
Very Low Reference Light

Low Reference Light



Optimum Reference Light

High Reference Light



Very High Reference Light

Figure 96 Different States of Reference Intensity

For optimal imaging, the reference intensity needs to be set accordingly. Please refer to the hardware manual of the Thorlabs OCT device for instructions on how to adjust reference intensity.

The reference intensity gauge is not available for Swept Source OCT engines.

3.3.2 Sensor Saturation (VEG200 & ATR200 Series Only)

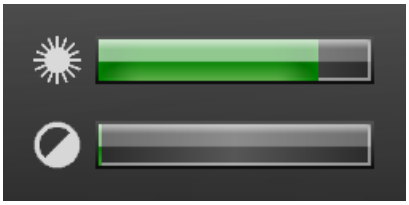
In the VEG200 and ATR200 series of OCT devices, a balanced detector is used to convert the optical OCT signal into an electrical signal, which is then digitized. To achieve optimal imaging, the amplitude of the electrical signal should match the dynamic range of the analog-to-digital converter.

Due to the balanced detection, this amplitude highly depends on both the amount of reference light being fed into the detector and the amount of light returned from the sample. Therefore, the interference-amplitude indicator in the menu bar should be consulted at each image acquisition and adjusted according to the instructions below. Additionally, a second indicator, located immediately below the interference-amplitude indicator in the menu bar, informs the fraction of saturation.

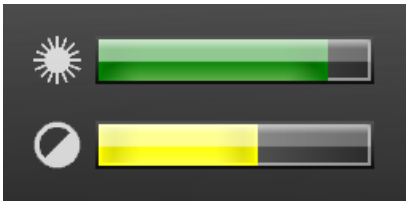
Ideally, one would maximize the amplitude of the interference - the higher, the better. Unfortunately, this is seldom possible over a scan without saturation at some points along the scan. Hence, the goal is to achieve an adequate interference-amplitude while keeping saturation within bounds (in some experiments, a small amount of saturation is acceptable).

Please note that both the interference-amplitude and saturation indicators are only updated when continuous image acquisition is running or after a one-shot acquisition is completed.

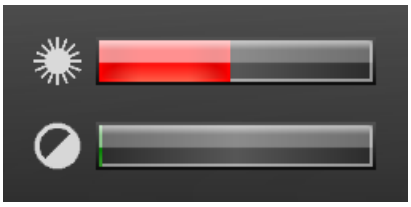
The following examples illustrate the main ideas.



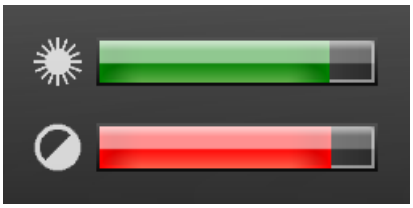
The interference amplitude is nearly ideal, with almost no saturating points. A quality measurement follows.



There is saturation at a few points along the scan, but at other points, the level of interference amplitude is nearly optimal. It might be possible to modify the scan pattern or slightly tilt the sample to avoid high reflecting points.



In this case, the interference amplitude is not sufficient for a good measurement. Try following the advice in the next section to tune the interference amplitude.



Quite a few points reach saturation. Changing the scan pattern or tilting the sample may help. However, the measurement will succeed at the points that do not saturate.

In some cases, the scan may pass over areas of high reflectivity, which can saturate the sensor. These points are considered when characterizing the level of saturation but are not included when computing the amplitude of interference.

Thus, two practical rules for the adjustment can be stated:

- Optimize the interference-amplitude with the hardware controls (amplification level & reference intensity) as described next. An interference amplitude in the green region usually correlates with a high quality measurement.
- Keep an eye on the saturation level, such that it remains low.

Adjustments for Optimal Interference-Amplitude

Devices from the VEG200 and ATR200 series of swept-source OCT systems are equipped with two hardware controls, which can be used to reach an optimal amplitude of interference:

Figure 97 Sensor Saturation Adjustments

These controls are available in all acquisition modes and can be accessed on the Dataset Parameters panel on the right hand side of the screen, in the category Device Settings.

Interference Amplitude and Sensitivity

Please note that the sensitivity which can be achieved with the OCT device highly depends on the chosen *Amplification Level* and *Reference Intensity*. The highest possible sensitivity can only be achieved by keeping the *Amplification Level* as low as possible and maximizing the amount of reference light.

Adjustment for Optimal Interference Amplitude

Depending on the sample that is being imaged, it may or may not be possible to actually adjust for perfect interference-amplitude. For example, a hypothetical, fully absorbing sample, will always yield zero interference-amplitude. In general, the following steps will lead to a good adjustment:

1. Start the desired acquisition, so that the indicators will be updated continuously.
2. Set both the *Amplification Level* and the *Reference Intensity* to the maximum value. This should lead to oversaturation. If no oversaturation is reached, this setting is as good as possible for the given sample.
3. Reduce the *Amplification Level* step by step until the oversaturation is eliminated, but the interference-amplitude remains at a good level. If the image interference-amplitude is now green, the optimal setting has been reached and the process is done.
4. If the amplitude of the interference is too low, increase the *Amplification Level* by one.
5. Reduce the *Reference Intensity* until the indicator of the interference-amplitude turns green.

3.3.3 Background Calibration (Swept Source OCT Only)

For optimal image quality, a background measurement must be performed. To achieve accurate results, remove the sample, ensure that no signal remains in the OCT image, and click the *Calibrate Background* button in the Action Toolbar.

Background measurements can be performed by pressing the *Calibrate Background* button.

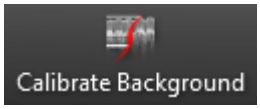


Figure 98 Calibrate Background Button

Please note that the *Calibrate Background* button is only visible for Swept Source OCT Systems. When working with Spectral Domain OCT systems (Callisto, Ganymede, Hyperion, Telesto, and Telesto II), manual background calibration is not necessary as the background measurement is automatically performed during device initialization.

3.3.4 Reference Length (VEGA & ATRIA Series Only)

For a Thorlabs VEGA imaging module or ATRIA imaging module, or a VEG200 or ATR200 series device, the toolbar will include reference stage controls in all data acquisition modes, as shown below on the right. These devices contain an integrated, motor-controlled reference stage. The reference length can be adjusted through a set of controls in the ThorImage®OCT.

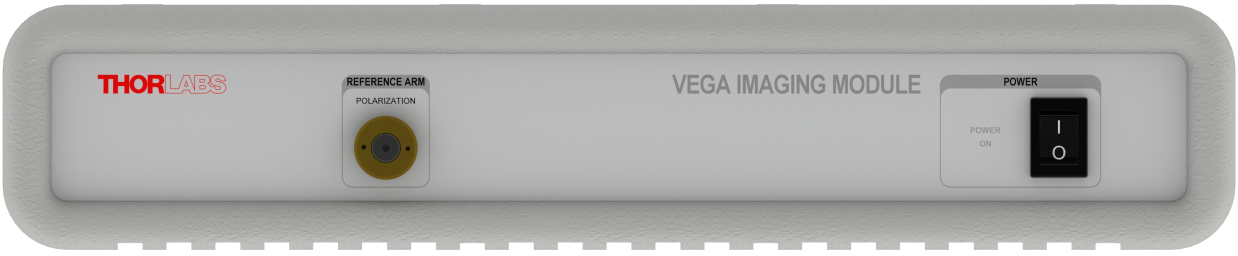


Figure 99 Thorlabs VEGA Imaging Module

Reference Stage Control

Figure 100 Reference Stage Control

Reference Stage Control Opitons (from Left to Right) in the Toolbar:

- Reference Length Indicator
- Fast Jog/Slow Jog Buttons
- Input Field

When ThorImage®OCT starts, the system will calibrate the motorized reference stage whenever it requires calibration. During this process, the *Reference Stage Control* will be blocked. However, the other aspects of ThorImage®OCT can be used while calibration is taking place.

Usually, the process of calibrating the reference stage should not take more than approximately 20 seconds, provided that the software has been properly closed before switching off the system after its last run.

Figure 101 Reference Stage During Calibration Process

Please note that the reference length displayed in the input field is relative to the zero delay line positioned at the very top of the OCT image. Thus, when the relative reference length is set to 0.000 mm, a good starting point for measuring can be obtained by positioning the probe height so that the primary peak of the sample is at the top of the OCT image.

The reference length/zero delay line calibration depends on the probe objective used. Thus, if switching the probe configurations using the Settings Dialog, the reference stage will move to maintain its position relative to the zero delay line with the new objective.

Moving the Reference Stage

The *Reference Stage Control* moves the stage in different ways:

1. Using the Jog Buttons
   a. Click and hold the *Jog* buttons to move the reference stage.
   b. Clicking one of the smaller arrows will move the reference stage slowly, similar to turning the Spectral-Domain systems scanning probe reference length adjuster.
   c. Using the larger arrows will result in faster movement.
   d. Clicking and holding an *Arrow* button will move the stage in the indicated direction until the *Mouse* button is released or the maximum/minimum length is reached.
2. Entering a Number
   a. Enter a number into the input field to immediately move the reference stage to the specified length.
   b. The controls will be locked during the movement.

The ThorImage®OCT will remember the last used reference length after each restart and subsequently move the stage during initialization. When the stage needs recalibration, the controls will be locked for the duration of the zeroing process, which may take approximately 30 - 40 seconds and will not happen very often.

3.3.5 Device Power/Standby

To use the ThorImage®OCT, the OCT device must be powered on. Some devices support software control of the power supply and can be fully turned off with a power switch at the back or be in standby mode (power indicator glows red). If the ThorImage®OCT starts while the device is off, the message "Device unavailable. "Please turn on device." will be displayed in the Action Toolbar.

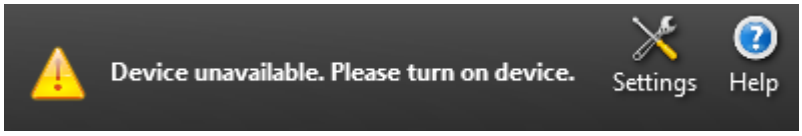


Figure 102 Action Toolbar Status "Device unavailable. Please turn on device."

In this case, turn on the device using the back power switch. If the ThorImage®OCT starts in standby mode, power it on via software by pressing the *Power On* button. The message "Device is powered off." will be displayed in the Action Toolbar.

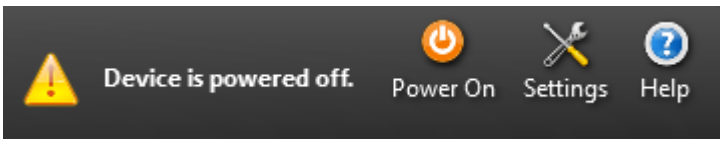


Figure 103 Action Toolbar Status "Device is powered off."

The device will turn on and the ThorImage®OCT will start.

3.3.6 Settings Dialog

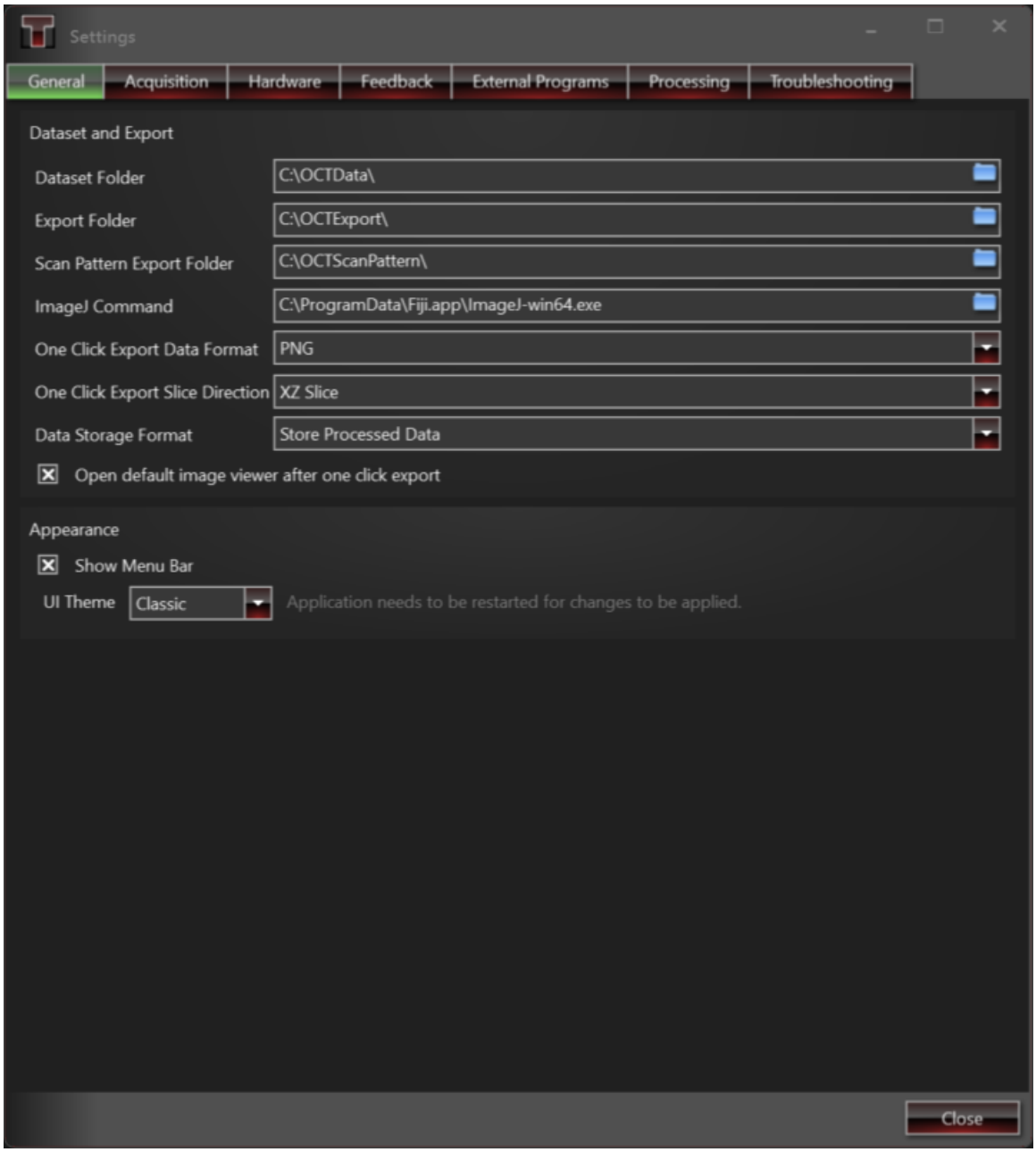


Figure 104 Settings Dialog

The Settings Dialog can be accessed via the *Settings* button on the right-hand side of the Action Toolbar. Alternatively, the Settings Dialog can be found under the drop-down menu of the File tab. The Settings Dialog offers global options that can be found throughout the application.

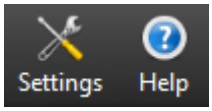


Figure 105 Settings Button (Toolbar)

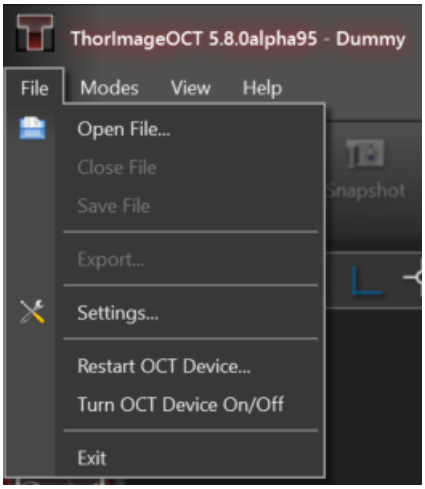


Figure 106 Settings Button (File Menu)

3.3.6.1 General

General

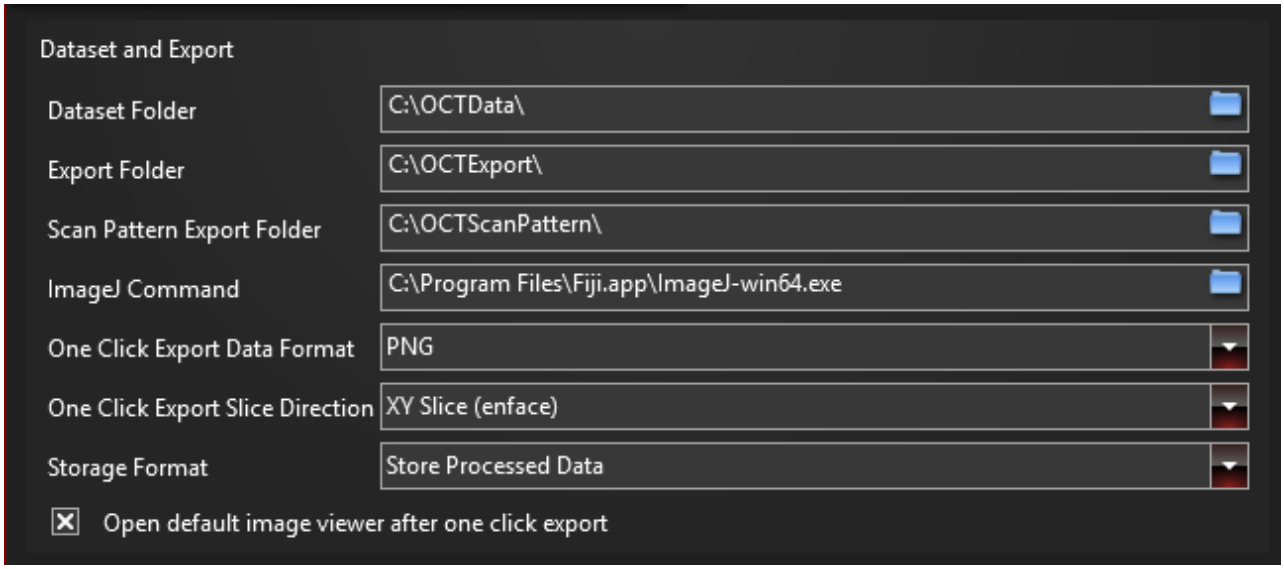


Figure 107 Dataset and Export Options in Settings Dialog

Dataset Folder
Recorded datasets will be automatically stored in the Dataset Folder.

Export Folder
When exporting data, the Export Folder will be used as default location.

Scan Pattern Export Folder
When importing/exporting a scan pattern, the Scan Pattern Export Folder will be used as the default location.

ImageJ Command
The ImageJ Command option sets the default command and path to be used to start the ImageJ application. A valid executable needs to be selected in order for the ImageJ command to show up when viewing datasets.

One Click Export Data Format

The One Click Export Data Format describes the default image export format that is used, for example, if the viewed dataset is to be opened by an image viewer. All export formats supported by ThorImage®OCT may be selected here, but not all datasets support all formats. For example, when trying to export raw data from a dataset that only contains processed data, an error message will be displayed.

One Click Export Slice Direction

When exporting volume datasets as images, they need to be sliced into individual images. The One Click Export Slice Direction option specifies the default direction for slicing. When exporting in a format that supports three-dimensional datasets, such as RAW or TIFF (32-bit), no slicing will be performed, and this setting will be ignored.

Data Storage Format

In the Data Storage Format options, which data are stored in the dataset files can be specified. Storing the processed data has the advantage that dataset loading and switching in the dataset list is fast. Storing spectral raw data enables reprocessing of data offline after it has been acquired. Storing both combines these advantages but comes at the cost of increased file size.

Open Default Image Viewer After One Click Export

The Open Default Image Viewer After One Click Export option is checked, the default Windows® image viewer is opened after performing the one click export.

Appearance

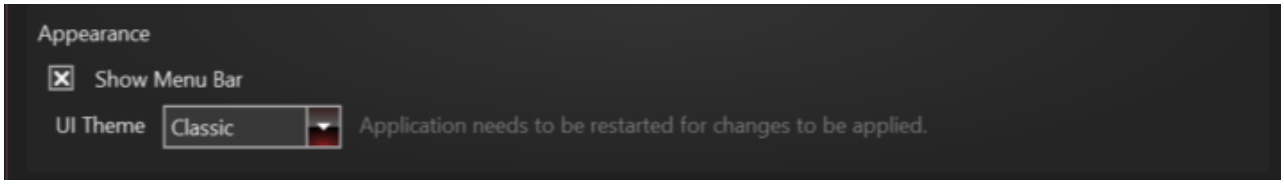


Figure 108 Appearance Options Box in the Settings Dialog

Show Menu Bar

The Show Menu Bar option toggles the visibility of the menu bar on and off. When this box is not checked, the menu bar can be brought up by clicking the *F10* or the *Alt* key.

Please see the section User Interface / Graphical User Interface for further information.

UI Theme

Via the UI Theme, you can change the look and feel of the graphical user interface. Two options are available:

- Classic
- Flat

Please note that changes will only take effect after restarting the software.

3.3.6.2 Acquisition

Mode Switch

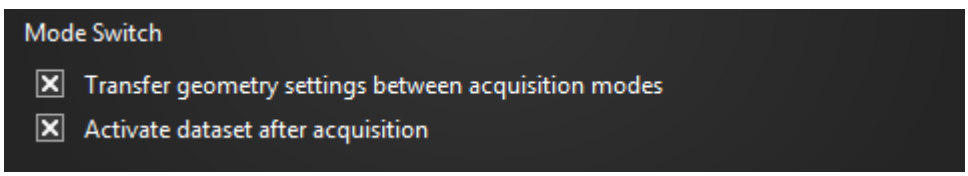


Figure 109 Mode Switch Options in the Settings Dialog

Transfer Geometry

When activating the *Transfer geometry settings* between acquisition modes option, the scan pattern is retained when switching acquisition modes, if possible. When switching from 2D to Doppler Acquisition Mode, the entire scan pattern is retained. When switching from 2D to 3D Acquisition, the B-Scan length (FOV X), the center position and the angle are retained.

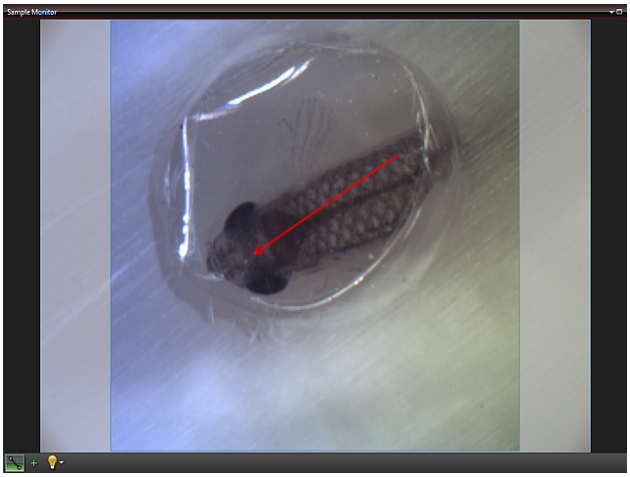


Figure 110 2D Acquisition (Left)
Figure 111 3D Acquisition (Right)

The scan pattern will be transferred when switching from 2D (left image above) to 3D Acquisition (right image above) if the transfer geometry settings between acquisition modes option is enabled.

Activate Dataset

When the *Activate data set after acquisition* option is activated, the data set is activated after acquisition and shown on the display. Deactivating this option is particularly useful in Speckle Variance Contrast Mode to deactivate data processing, which can take longer than the acquisition. To do this, the storage format must be set to Spectral Raw Data.

Time Series

Figure 112 Time Series Options in the Settings Dialog

Automatically Open Time Series Datasets

If the *Automatically open time series datasets* option is activated, datasets that have been recorded with a time series are automatically opened and displayed in the list of datasets. With long time series, this can overload the list and lead to memory problems. To avoid this, the option can be deactivated. Time series datasets are then saved in the current study folder and can be opened manually later.

General Acquisition

Figure 113 General Acquisition Options in the Settings Dialog

Disable B-Scan Size Limit

Normally, ThorImage®OCT limits the size of B-Scans to 10 000 points. If the Disable B-Scan size limit option is activated, this limit is removed, allowing acquisitions with very large B-Scan sizes. These may be useful in special application cases such as vibrometry measurements. Please note that overly large B-Scans are not supported by all OCT Imaging Systems and may lead to system crashes. Additionally, datasets with overly large B-Scans will not be rendered in ThorImage®OCT, but may be exported to be used with third-party software.

Disable Acquisition of Apodization Data in Scan

The Disable acquisition of apodization data in scan setting and the following explanation only apply to spectral domain OCT Imaging Systems. By default, before each OCT-Scan, the system moves the scan beam to a position outside of the field of view. Once this position is reached, a calibration measurement is acquired (the apodization spectrum). If this is inconvenient for your experiment, enabling this setting will skip the measurement of this calibration data.

Apodization spectra are essential for the processing of the raw data. Enabling this setting may considerably affect the image quality of the scans. If in doubt, leave it unchecked.

If checked, the acquisition toolbar will be augmented with buttons for calibration of the apodization spectrum. There are the following two options:

- **Use Scan**
  The actual scan can be used as calibration.
- **Measure**
  A particular spectrum can be manually measured.

Please note that the manual calibration cannot be performed during an acquisition.

Figure 114 Alternative Options for Calibration

When a new dataset is acquired or an existing data is opened, the source of the apodization data is displayed in the processing section.

3D Acquisition

Figure 115 3D Acquisition Options in the Settings Dialog

Disable Dynamic 3D Resolution

When checked, 3D volumes are always rendered in full resolution. This may lead to degraded performance when interacting with a 3D display for large datasets. See the section Volume View for details.

Render Large Volumes

The Render large volumes option allows rendering of larger volumes that might exceed the available memory. Please note that this feature is experimental and might lead to crashes.

Disable Memory Check

By default, the ThorImage®OCT checks whether sufficient free memory is available before a volume scan is performed. In some cases, this check may be incorrect. Activating the Disable memory check setting deactivates the check.

Please note that acquiring very large volumes can cause the ThorImage®OCT or the entire system to crash.

3.3.6.3 Hardware

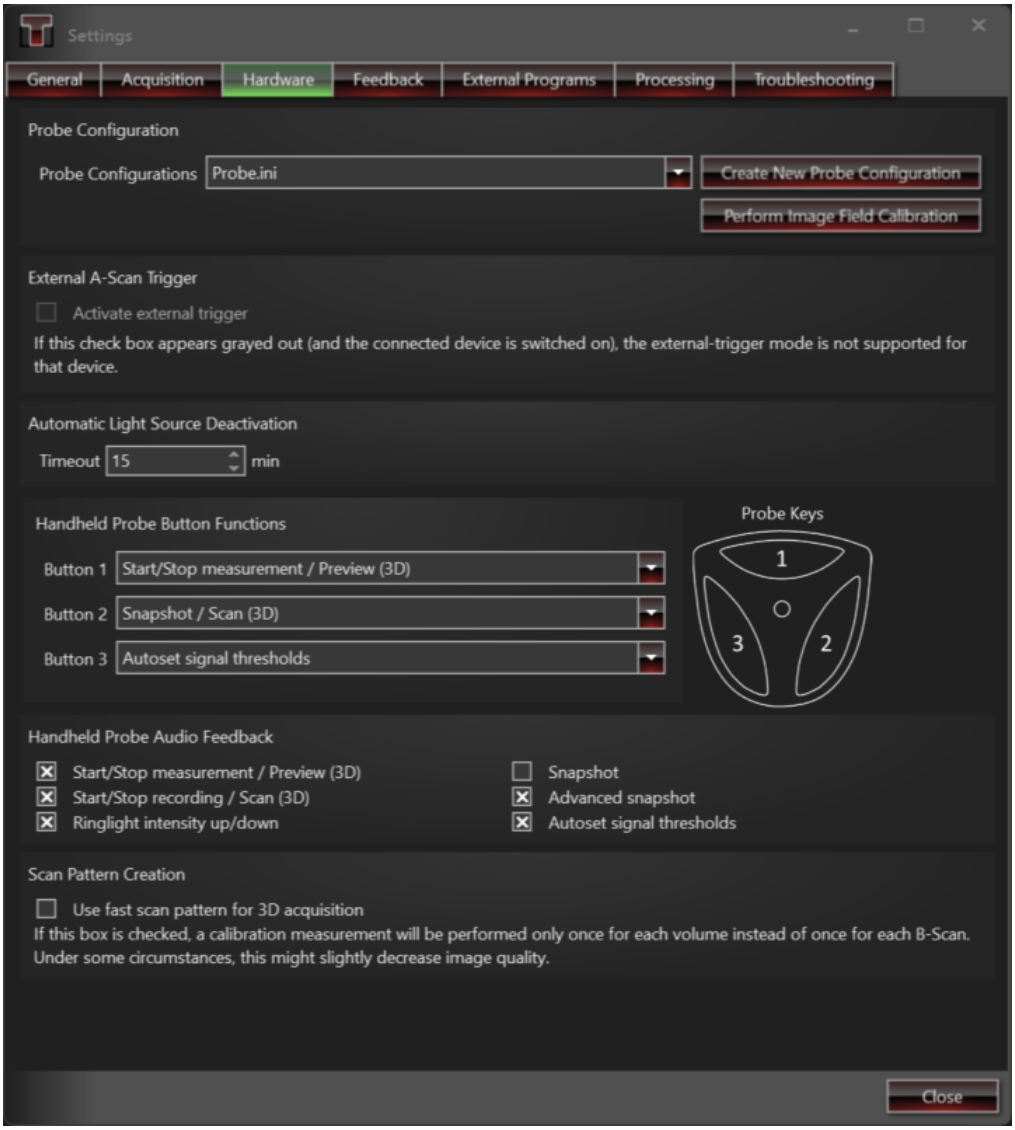


Figure 116 Hardware Tab in the Settings Dialog

Probe Configuration

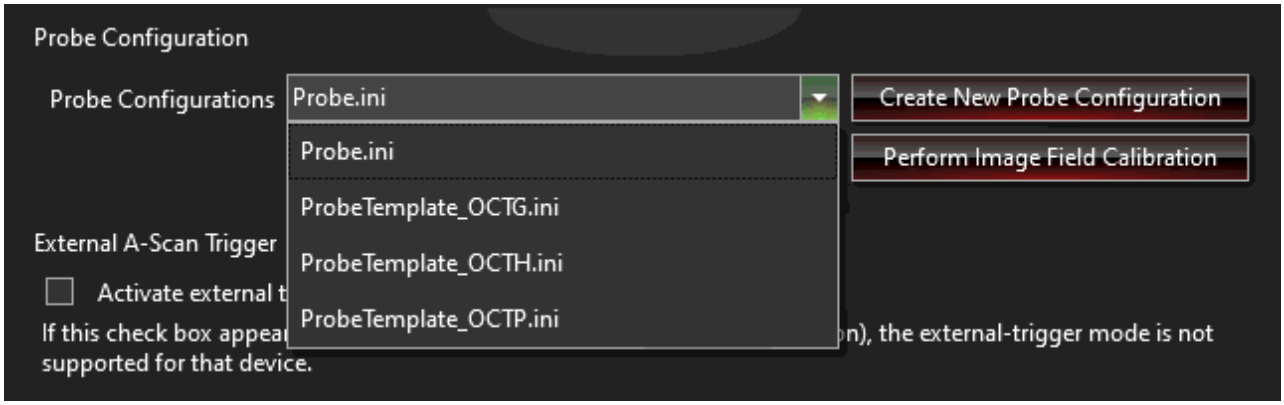


Figure 117 Probe Configuration Choice

Different scanners and objectives will have different configurations. These configurations contain information about the optical properties of the objective lens as well as correction factors for the Draw & Scan feature. Make sure to have the matching probe configuration selected in this drop-down menu when changing probes or probe objectives.
If the probe objective is not listed, a new probe configuration can be generated by clicking the *Create New Probe Configuration* button. Please see the following section Probe Calibration for details about the probe calibration process.

In order to only update the image field correction matrix for the selected probe configuration, click the *Perform Image Field Calibration* button. This will bring up the Image Field Calibration step of the probe configuration dialog to start the recalibration process.

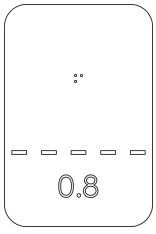
Ensure that the surface or sample under the objective is flat, smooth, and level.

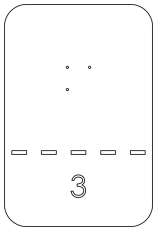
Probe Calibration

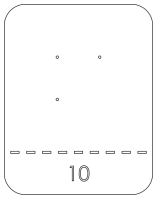
When changing the objective of the OCT probe, the Probe Configuration in the settings dialog needs to be changed as well. If no configuration file for an objective is available, a new probe configuration can be generated using the probe calibration tool.

The probe configuration tool can be opened by clicking *Create New Probe Configuration* in the Settings Dialog. The probe calibration tool will then guide you through the various steps that are necessary to generate the configuration file.

For this procedure, we recommend mounting the probe on its stand so that the objective points downwards. The probe calibration requires a calibration sample to be positioned under the probe. A specific calibration target is required for each different objective. If the OCT wavelength lies outside the visible range, the IR card included in the Thorlabs OCT system package will be necessary.

Either 

or 

or 

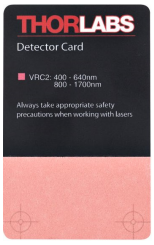
and 

Figure 118 (Left) Three Probe Calibration Samples
Figure 119 (Right) IR Card

Enter Probe Type

In the first step of the probe configuration process, the probe type must be specified. This includes the used objective (LSM02, LSM03, LSM04 and LSM05) and the probe serial number that is printed on the probe reference arm (the latter is optional).

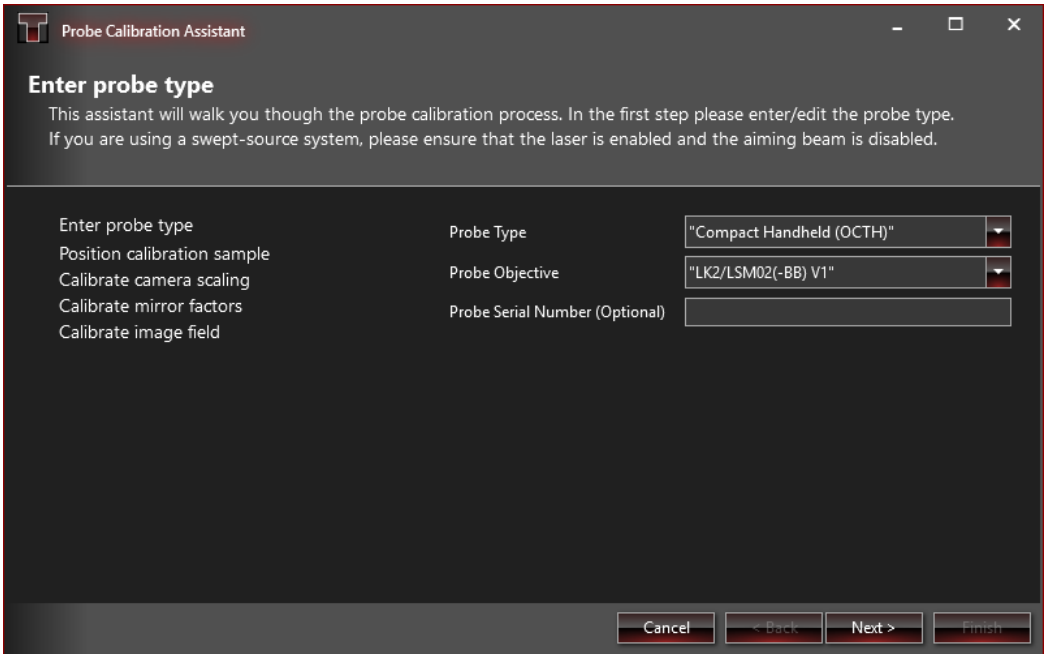


Figure 120 Enter Probe Type

After clicking *Next*, the required probe calibration sample is shown. It is essential to use the correct calibration sample as shown in the window. Right now three different calibration samples are available. If you do not have the correct calibration sample for your objective on hand, please contact Thorlabs.

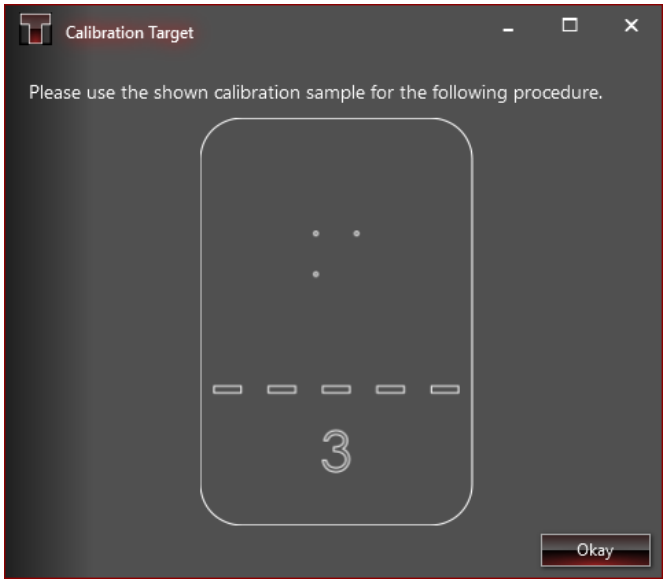


Figure 121 Calibration Sample with 3 mm Hole Distance

Position Calibration Sample

In the second step, the calibration sample must be placed under the probe such that the three holes are positioned in the center of the video image. It is also essential that the sample is in the focus of the probe to ensure a sharp image. Please adjust the height of the probe using the height adjustment knobs of the stand such that a sharp image is visible.

If the sample is detected correctly, a red cross will be displayed in the center of the markings which needs to be contained within the blue square. For some objectives, it is also required that the calibration sample is positioned in the same orientation as the camera image.

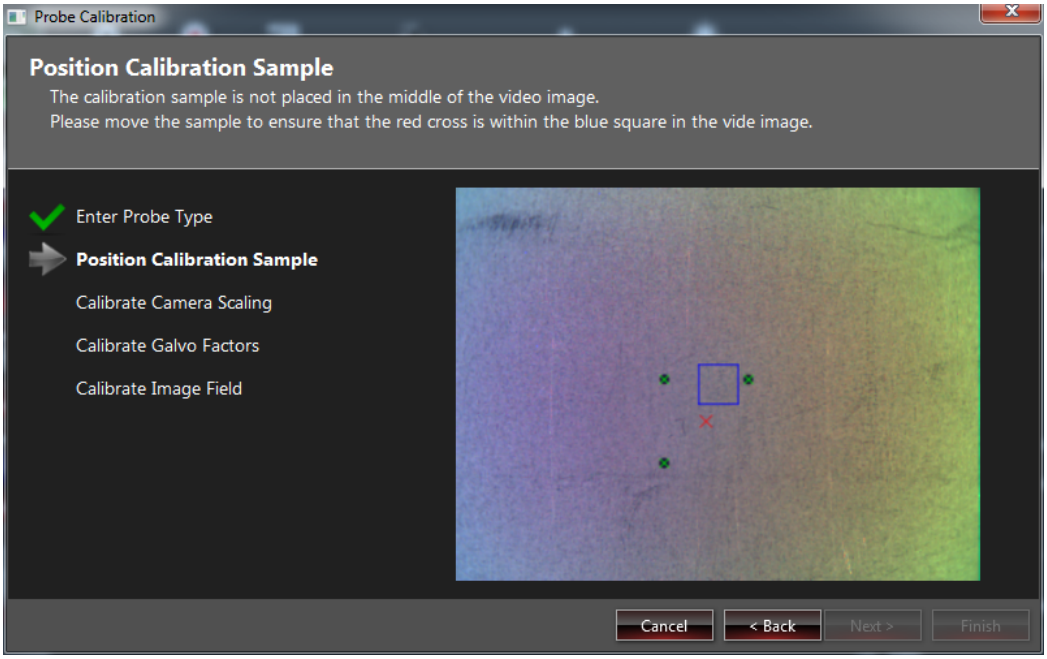


Figure 122 Positioning of the Calibration Target

When the calibration sample is positioned correctly, the cross and the square will turn green.

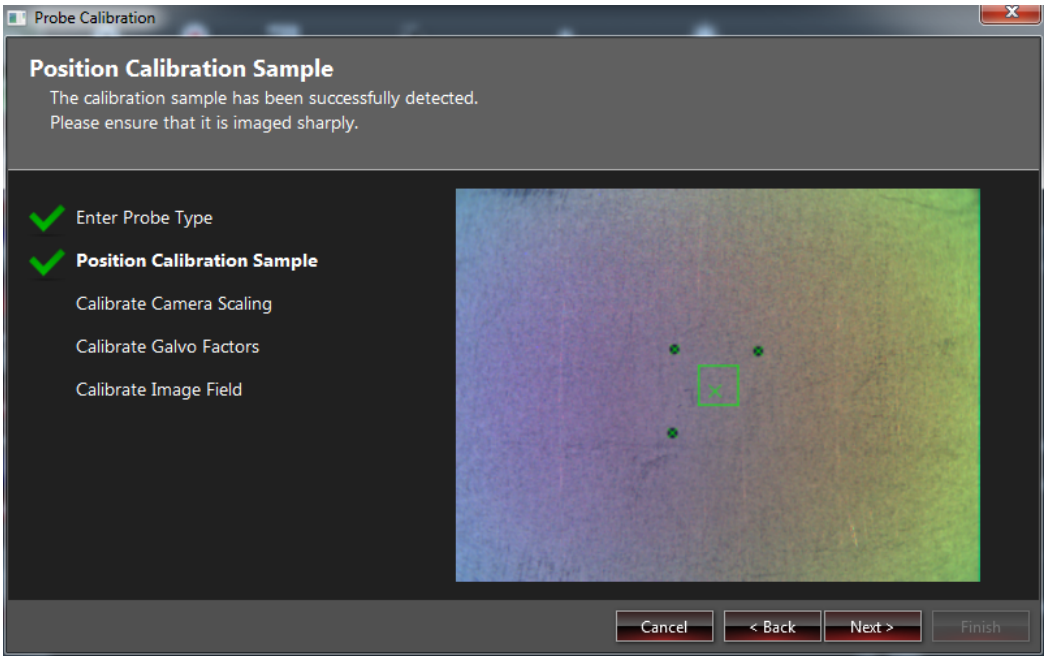


Figure 123 Correctly Positioned Calibration Target

Camera Scaling and Galvo Factors

After positioning the calibration sample, the camera scaling and galvo factors will be automatically determined. If this step fails, you can either retry by clicking *back* and *next* again, or retry the calibration procedure using an IR card.

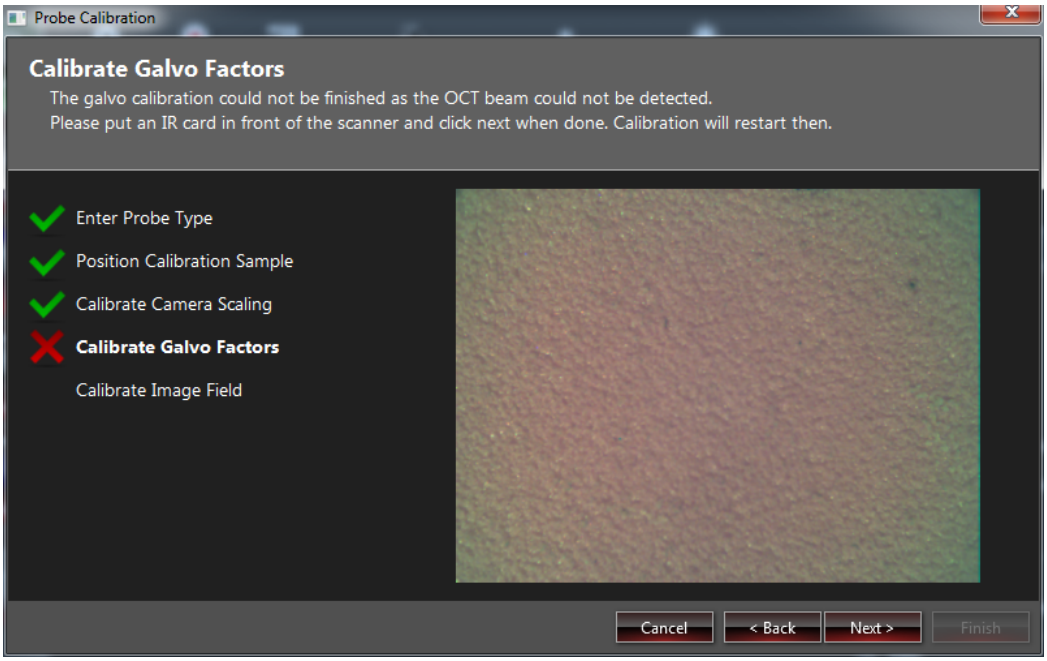


Figure 124 Recalibration of Galvo Factors Using an IR Card

Image Field Calibration

In the last step the image field will be calibrated. If the IR card has been used in the previous steps, please remove it and place the calibration sample below the probe once more.

Image field calibration is done in two steps. First, a continuous B-Scan preview is used to adjust reference intensity and reference path length in such a way that the surface of the calibration target is clearly detected. In the second step, the full image field is measured.

If everything has been adjusted correctly, the B-Scan of the image field preview looks as shown in the figure below, and automatic image field calibration will take place.

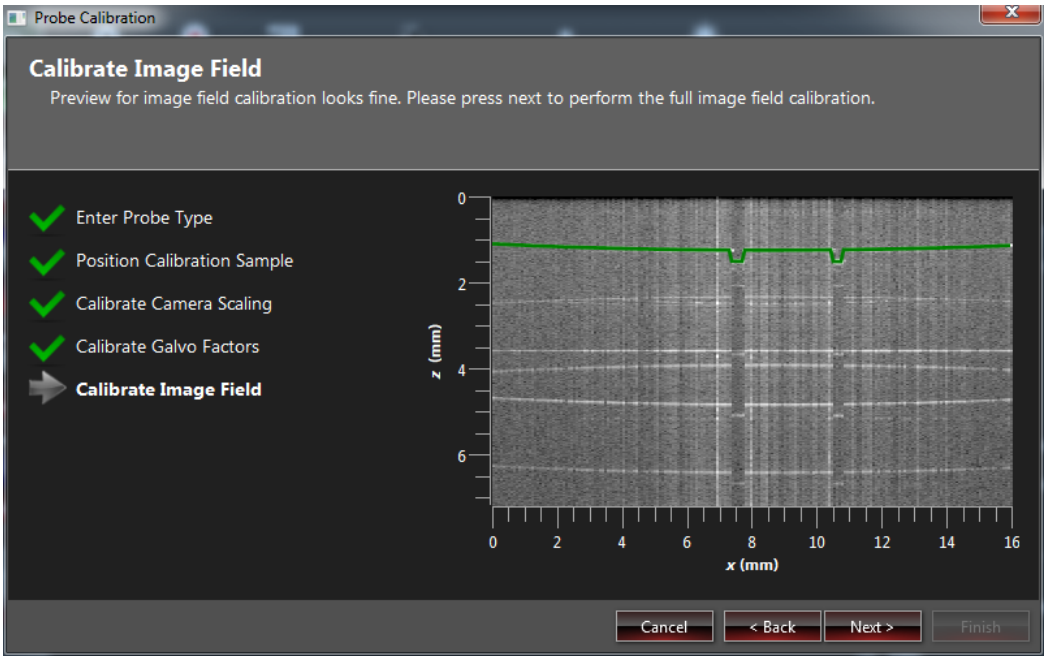


Figure 125 Surface Successfully Detected

If the sample surface fails to be detected, please follow the instructions given in the following paragraphs to improve imaging quality.

No Surface Detected

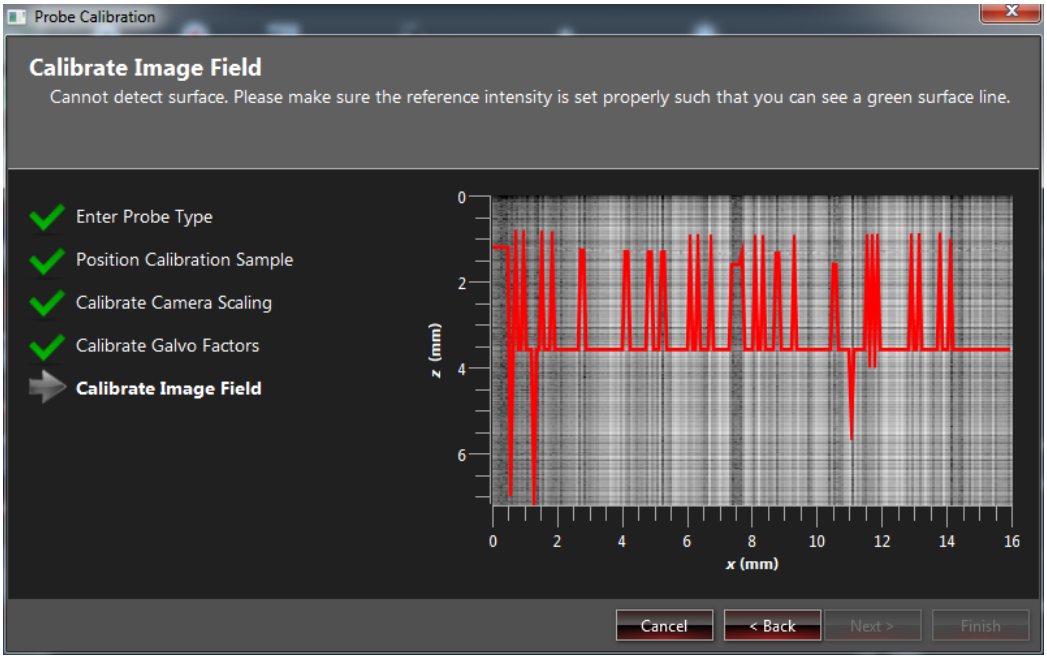


Figure 126 No Surface Detected During Image Field Calibration

When the image looks as in ***Figure 126***, no surface has been detected yet. There are several possible reasons for surface detection failure.

1. The reference intensity might not be set correctly
   ➤ This can be adjusted using the knob in front of the probe.
2. The reference path length might be misaligned.
   ➤ This can be adjusted using the knob on top of the probe.
3. The calibration target might not be in the focus of the probe.
   ➤ This can be adjusted by changing the distance between probe and sample.

Please adjust these parameters individually until the detected surface shows up green.

No Holes Scanned

The preview image field calibration should scan through one or more holes of the calibration sample. If the scan looks as follows, the previous calibration could not be determined correctly. Please go back and recalibrate the galvo factors.

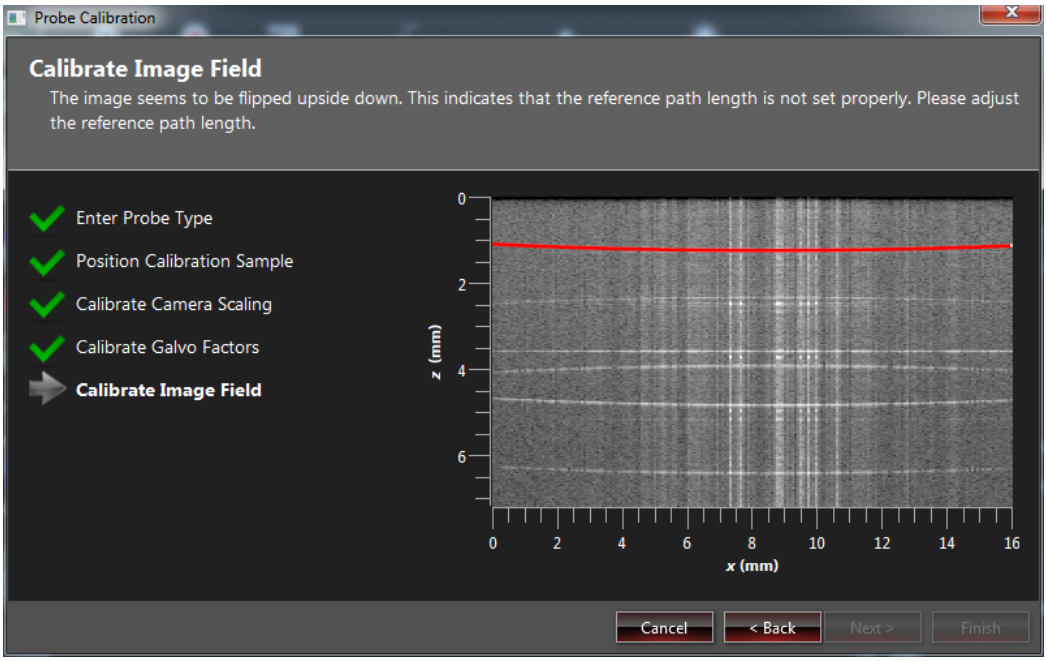


Figure 127 No Holes Scanned During ImageField Calibration

Image Flipped

If the reference path length is wrong, the image might be flipped upside down. In this case, the reference path length needs to be adjusted using the knob on top of the probe until the holes are below the remaining surface.

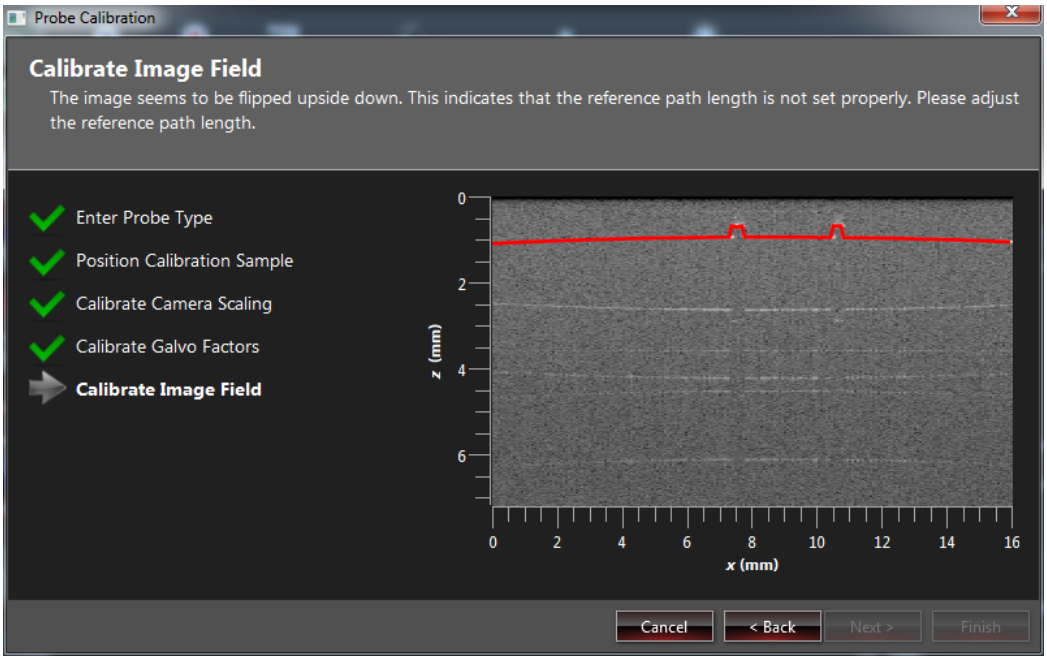


Figure 128 Image is Flipped Upside Down (Holes in the Calibration Cample are Shown on Top)

Surface found: Image Field Calibration

If the surface precalibration has been successful, the image field calibration will be performed.

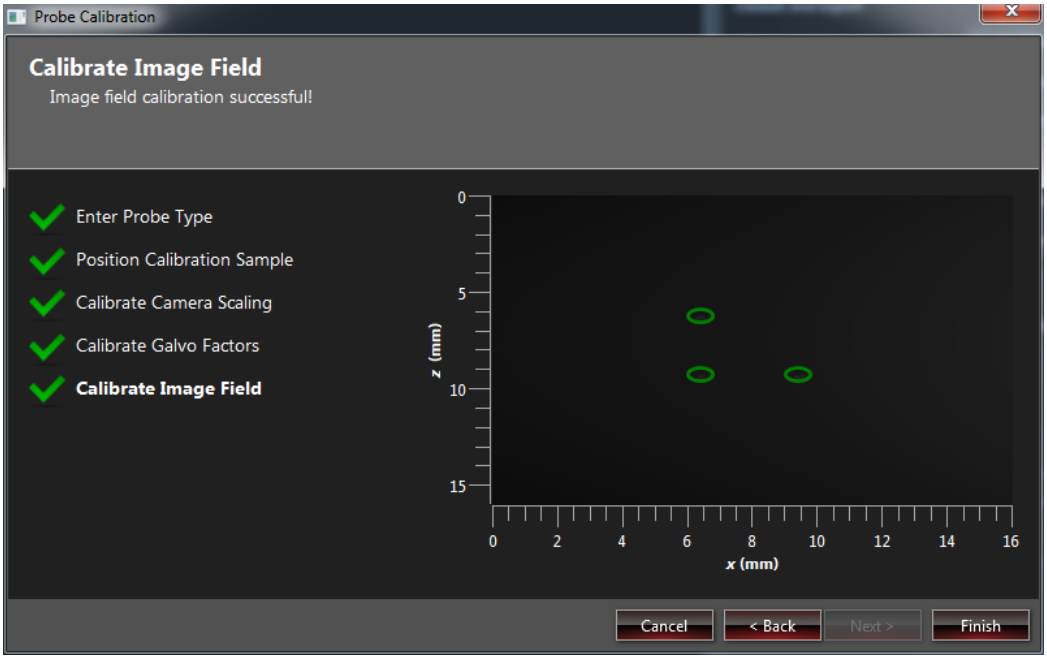


Figure 129 Successful Image Field Calibration

Clicking the *Finish* button closes the Probe Calibration dialog and the resulting probe configuration file will be written. The new probe configuration will be available afterwards in the probe combo box in the Settings Dialog.

External A-Scan Trigger

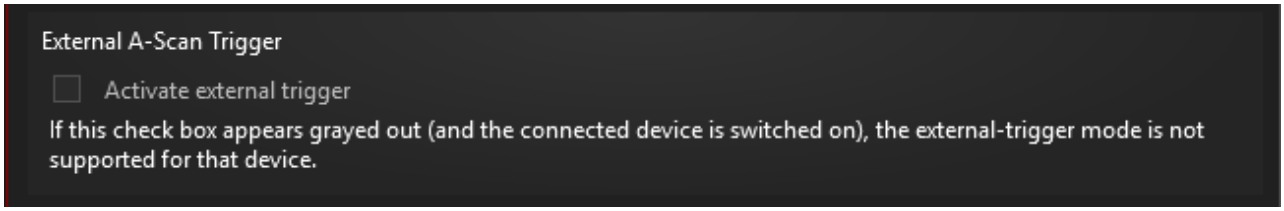


Figure 130 Activation of the External A-Scan Trigger Mode

Many Thorlabs OCT devices support synchronization of the OCT-Scan to external trigger sources (see section External Triggering).

The *External A-Scan Trigger* feature can be activated on the hardware page of the settings dialog using the check-box.

Base Unit Power Supply

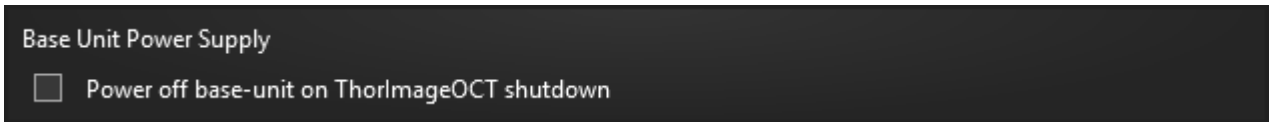


Figure 131 Base Unit Power Supply

Some OCT devices support software control of the power supply. On these devices, the check-box can be enabled, to automatically power off the base unit whenever the ThorImage®OCT is closed.

This does not constitute a laser safety feature, as the power off sequence may fail, for example in case of software crashes.

Automatic Light Source Deactivation

Figure 132 Automatic Light Source Deactivation

This option provides the ability to extend the life time of the ThorImage®OCT and to automatically switch off the light source after a certain time. Depending on the specific use pattern, the user can decide the desired timeout here.

Handheld Probe Configuration (Optional)

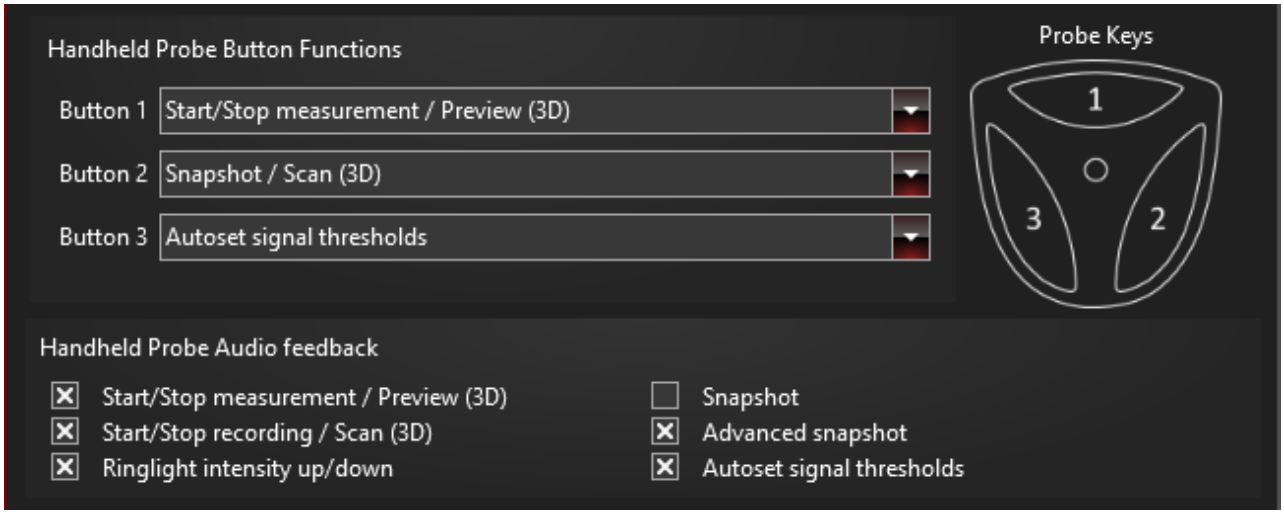


Figure 133 Handheld Probe Configuration

If If a Thorlabs OCTH handheld probe is connected to the OCT Imaging System, the settings dialog will provide some options specific to the handheld probe. These comprise the configuration of the three buttons of the handheld probe, as well as toggling audio feedback on key system events.

Handheld Probe Button Functions

You can assign one of a number of functions to each one of the three buttons in the handheld probe. The following options are available:

- **Start/Stop measurement/Preview (3D)**
  Toggle image acquisition on/off; in 3D acquisition this will start and stop the preview function.
- **Start/Stop recording/Record (3D)**
  Toggle recording on/off; in 2D Acquisition/Doppler Acquisition Modes, when this is pressed during a running acquisition, the acquisition will not stop after recording has been stopped.
- **Increase Ringlight Intensity**
  This is similar to adjusting the ring light slider upwards (see section Sample Monitor/Ringlight).
- **Decrease Ringlight Intensity**
  See Section Sample Monitor/Ringlight
- **Snapshot**
- **Advanced Snapshot**
- **Autoset Signal Thresholds**
  See the section Coloring Control for further information.

Handheld Probe Audio Feedback

Use the check-boxes to toggle audible feedback for the Handheld Probe Button Functions listed above.

Extra hardware (speakers/headphones) may be necessary to hear the audio feedback. Modern PCs usually come with onboard sound cards; there should be one or more 1/8" jacks on the PC's backpanel for connecting headphones or speakers. Please refer to the appropriate hardware user guide to learn how to connect audio hardware.

Scan Pattern Creation

To create 3D volumetric scan patterns there are two options that can be selected in the options dialog.

Normal

A normal scan pattern is created that performs one calibration scan per B-Scan. This ensures optimal image quality, but imaging speed can be slightly reduced. The *Scan Pattern Creation* option is activated if the *Use fast scan pattern for 3D acquisition* check-box is not set.

Fast 3D Scan Pattern

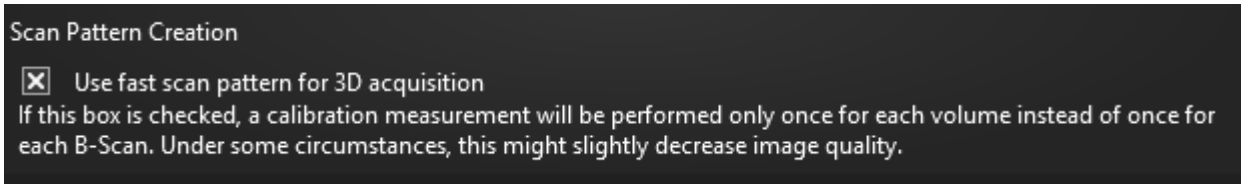


Figure 134 Check-Box for Activating Fast Scan Pattern Option

The system performs only one calibration scan for an entire 3D volume if the check-box *Use fast scan pattern for 3D acquisition* is checked. This decreases the total acquisition time.

Accurate computations require frequent recalibrations, which take into account small drifts. Hence, activating this option might decrease the image quality if the calibration measurements stop being frequent. Users interested in the speed gained with the help of this feature may gain insight by experimenting with a static sample, and then comparing the images obtained with and without this option.

3.3.6.4 Feedback

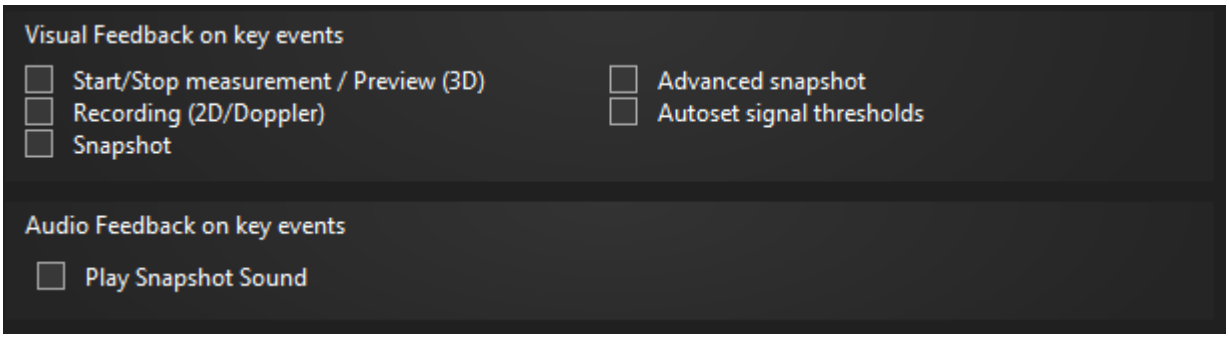


Figure 135 Audiovisual Feedback Options

Visual Feedback on Key Events

Toggling these check-boxes will provide visual feedback on the listed events. Visual feedback will be either the toolbar or the display background flashing.

Audio Feedback on Key Events

When the Audio Feedback on key events check-box is checked, an audio signal will be provided for the listed events. Currently only the snapshot event provides optional audio feedback. Please see also the section Handheld Probe Audio Feedback.

3.3.6.5 External Programs

The external programs section of the settings dialog allows the definition of calls to third-party software to open datasets by user-specified 3rd party or user-developed programs with a single mouse click. This feature may be used to display, process, and/or modify data in third-party applications and then feed the modified data back to ThorImage®OCT.

If a dataset is opened with an external program it will be exported to a temporary file. The external program will be called with arguments indicating the path to the exported dataset and file size, if necessary. The external program can then process the data and the ThorImage®OCT can reopen and display the modified data afterwards.

Third party programs must be able to read data of one of the export formats via its command line. Various additional information can be provided through further command-line parameters.

To add a new external program to the list click on the *Add* button in the external programs section of the dialog. Program specifications can be removed or changed with the *Remove* or *Edit* buttons respectively. Adding or editing an external program specification will open the external program specifications dialog.

External Program Specifications Dialog

The External Program Specifications dialog contains the following configuration items:

Name

The content of this field will appear in the drop down menu of the External Program button when viewing a dataset.

Command

The external program to call and open the dataset. This needs to be a fully qualified path to an executable or command script.

Arguments

Command line arguments provided to the external program. The following options are available:

***%f*:** Path and Output File Name of the Exported Temporary File that Contains the OCT Data

***%z*:** Data Size in z (Number of Depth Pixels)

***%x*:** Data Size in x (Number of A-Scans in Each B-Scans) → This value is 1 if a single A-Scans is Exported.

***%y*:** Data Size in y (Number of B-Scans in a Volume) → This value is 1 if a single B-Scan is exported.

***%i*:** Fully Qualified File Name of the Modified Data → If readback is enabled, the ThorImage®OCT will read this file after execution of the external application and display it as an OCT dataset.

Format

File format used for both export into a temporary file and readback of modified OCT data.

Supported formats are:

- **RAW (32-bit Floating Point)**
- **TIFF (32-bit Floating Point)**
- **Complex RAW (32-bit Floating Point)**

  For the complex valued 32-bit RAW export, the readback function is currently not available.

Wait For Process to Finish

If this option is activated, the ThorImage®OCT will wait for the external program to quit before continuing normal operation. This is required if the temporary file is to be deleted after reading or if modified data is to be read back into ThorImage®OCT.

Delete Temporary File

The ThorImage®OCT will delete the temporary file after the external program's process finishes.

Open Modified File after Execution Finished

This options enables readback of modified data into the ThorImage®OCT and allows displaying of the modified data in place of the original dataset. The external program must write this data to the file specified to the external program by the ***%i*** command line argument before it exits. Displaying the modified data is currently only supported in the 2D and 3D acquisitions.

Use Original Input File to Re-Open Modified Data
The ThorImage®OCT expects the modified data to be in the originally provided file. Please note that in this case the ***%f*** and ***%i*** command line arguments will resolve to the same path.

Delete Modified File
Deletes the file containing the modified data after being read by ThorImage®OCT.

The parameters for the corresponding external program specification can be found in the script's comment section and in the following screenshot.

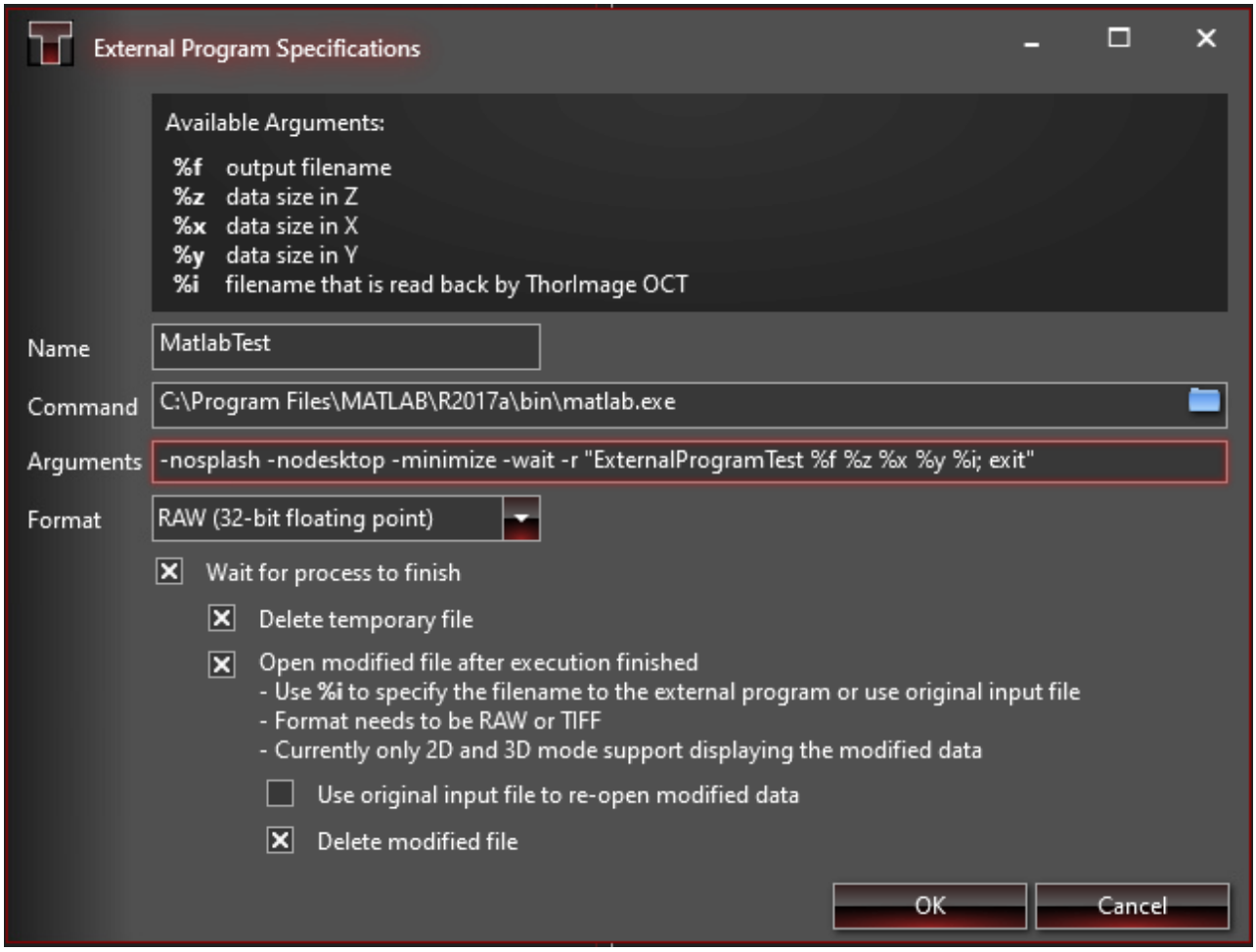


Figure 136 External Program Specifications

The parameters for the corresponding external program specification can be found in the script's comment section and in the following screenshot.

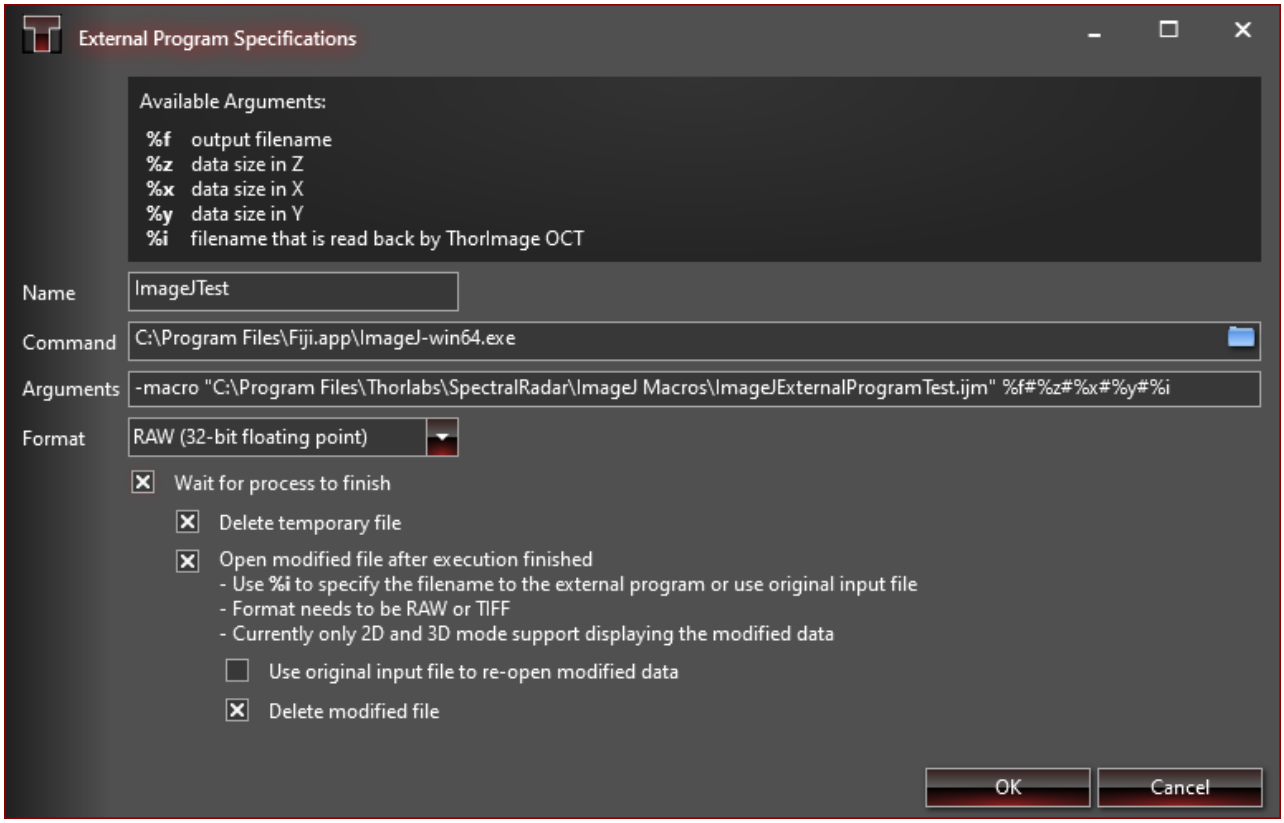


Figure 137 External Program Specifications

Please note that a MATLAB® sample script is provided in ExternalProgramTest.m, located in
C:\Program Files\Thorlabs\SpectralRadar\Matlab\Examples
by default.

3.3.6.6 Processing

With the Processing section enabling or disabling Python processing is possible. This feature is experimental and should be used with care.

Enable Python Processing: Enables Python Processing modes, the system needs to meet the requirements.

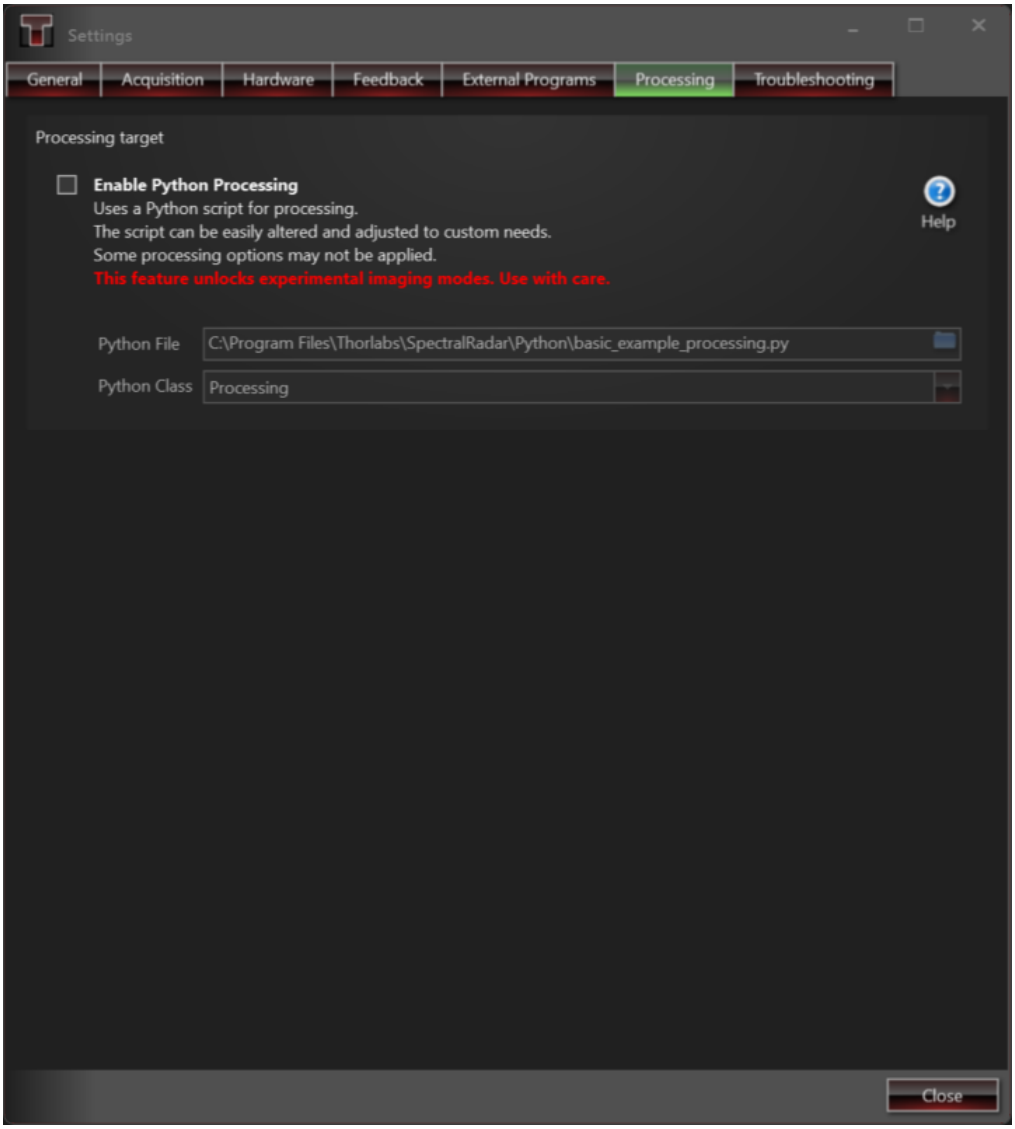


Figure 138 Processing Tab in the Settings Dialog

After Python processing has been activated, a Python file can be selected and a class contained therein that implements the processing.

Python File

The *Python File* contains the implementation of a processing class as well as a parameter class. The former provides entry-points for the processing while the latter provides parameters that can be shared with the ThorImage®OCT software.

The processing class must inherit from the "AbstractProcessing" class within "*C:\Program Files\Thorlabs\SpectralRadar\Python\ThorImageProcessing\ext\abstractprocessing.py*". The basic processing examples can be used as a blueprint. The "UserParametersExample" class within "*C:\Program Files\Thorlabs\SpectralRadar\Python\ThorImageProcessing\basic_example_processing.py*" shows how to define parameters in python that can be controlled through ThorImage® OCT.

Warning. Do not change any files in the *C:\Program Files\Thorlabs\SpectralRadar\Python\ThorImageProcessing\ext* folder.

Python Class

A python file might contain multiple processing classes. The *Python Class* which the user wants to use for the processing should be selected.

3.3.6.7 Troubleshooting

Figure 139 Troubleshooting Tab in the Settings Dialog

The tab Troubleshooting shows the following options:

1. Show the logfile.
2. Restart the device.
3. Reset the software configuration.
4. Reset the camera.
5. Reset the device configuration.

For further information see the chapter Troubleshooting.

3.3.7 Help

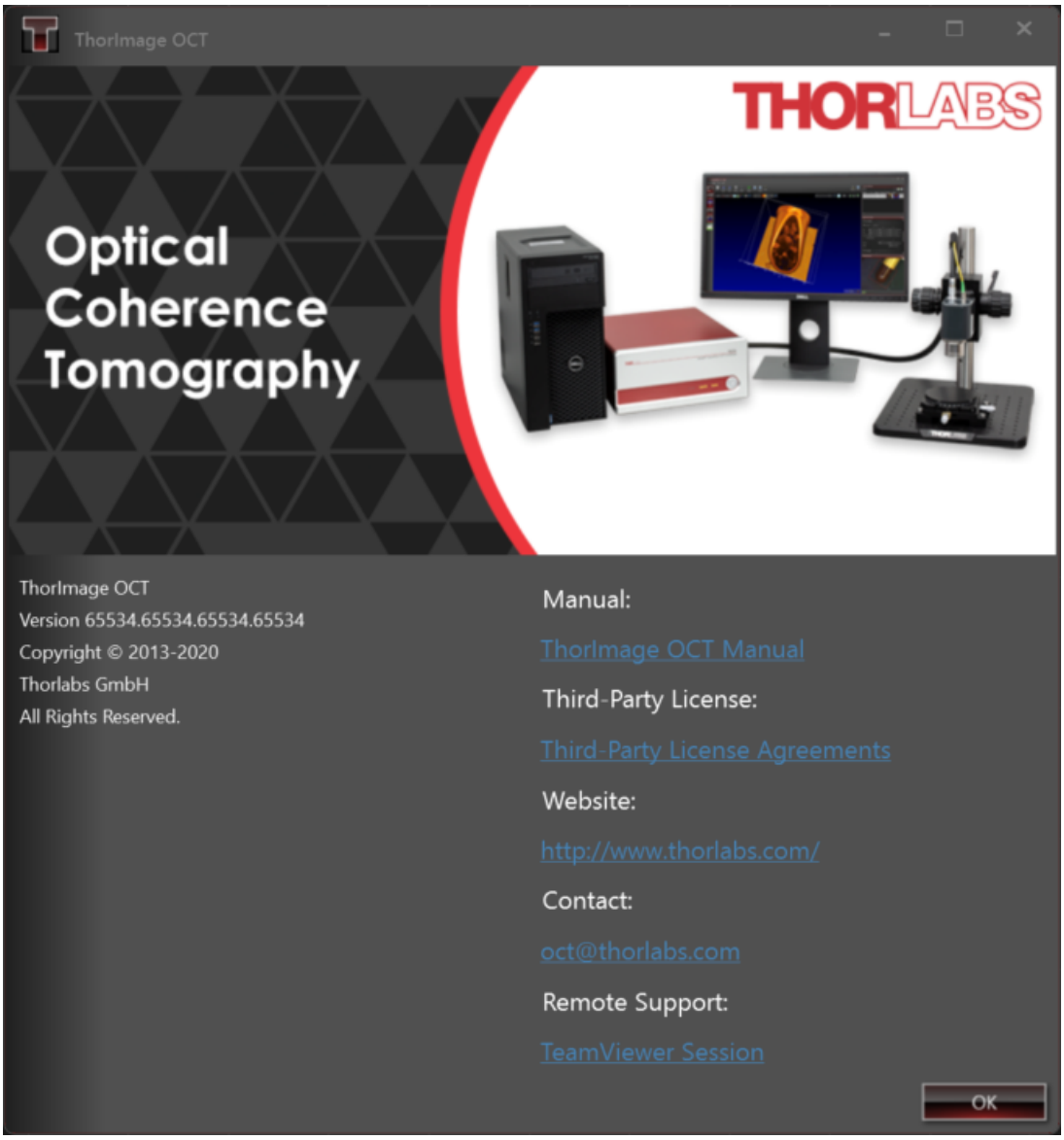


Figure 140 Help Window

This section provides information about the ThorImage®OCT version and quick access to the following resources:

- ThorImage®OCT Manual
- Third-Party License Documentation
- Thorlabs Main Website
- Email Contact for OCT-Related Support
- Link for Remote Troubleshooting with Thorlabs Support Engineers via TeamViewer

3.4 Display Toolbar

When viewing live or offline OCT data, the display can be adjusted using the controls available here. These include setting color modes, selecting aspect ratios, performing distance measurements on the current data, or showing a single A-Scan in a B-Scan.

The corresponding toolbars for the associated modes can be found under the following links:

- 1D Aquisition
- 2D Aquisition
- 3D Aquisition
- 2D Polarization-Sensitive Mode
- 3D Polarization-Sensitive Mode

3.5 Data Handling

3.5.1 Captured Datasets

Dataset management is realized using the Captured Datasets control. The Captured Datasets control lists previously acquired or loaded datasets with identifiers (study name and experiment number), acquisition mode, and preview images from the probe camera and OCT images.
Left-click a dataset to highlight and display it in the Sample Monitor and OCT displays. Multiple datasets of different acquisition modes can be opened simultaneously, but only the OCT data of the active dataset is kept in main memory. The active dataset is shown in bold (e.g., Default 82). Unsaved changes are marked with an asterisk (*). Select multiple datasets by left-clicking while holding *Shift* or *Control Key*, or by right-clicking. Selected datasets are highlighted with a light gray background.

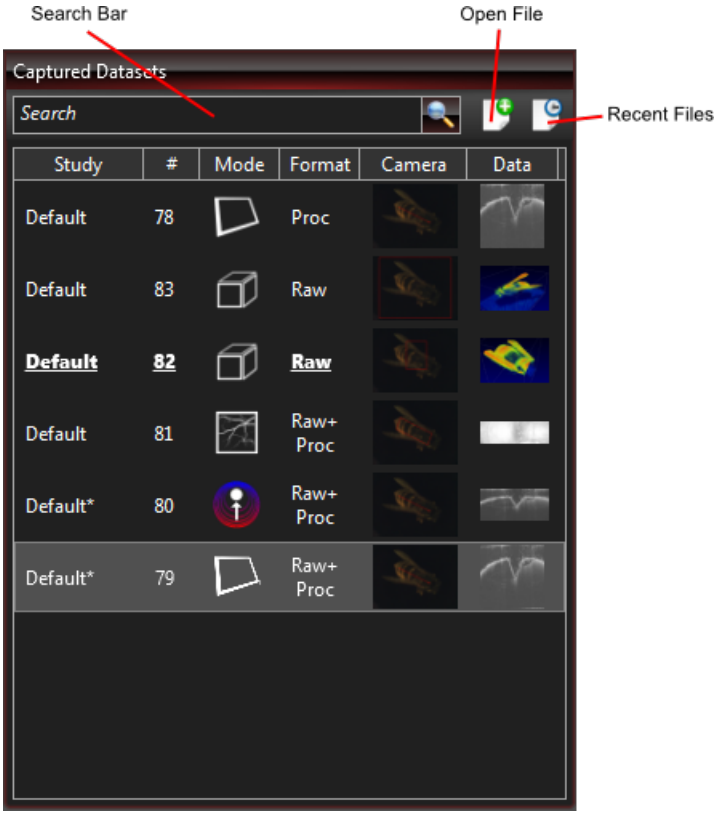


Figure 141 Captured Datasets Control Window (Overview About All Opened Datasets)

3.5.2 Dataset Location

Each captured dataset is stored in the *DatasetFolder*, which can be set in the Settings Dialog. Each study has a folder containing the OCT data files, allowing multiple datasets to be grouped by study name. Each dataset has a unique experiment number, incremented with each new dataset. The full path of the dataset is composed as follows:

DatasetFolder\Study\Study_ExperimentNumber_Mode.oct

The datasets are stored in the proprietary Thorlabs OCT data format (see section File Format for details).

3.5.3 Closing/Deleting Datasets

By right clicking on one or several selected datasets in the dataset list, the selected file(s) can be closed or deleted. Closing removes them from the list, while deleting also deletes the dataset file from disk.

The Context Menu appears when right-clicking on a selected dataset (see image below).

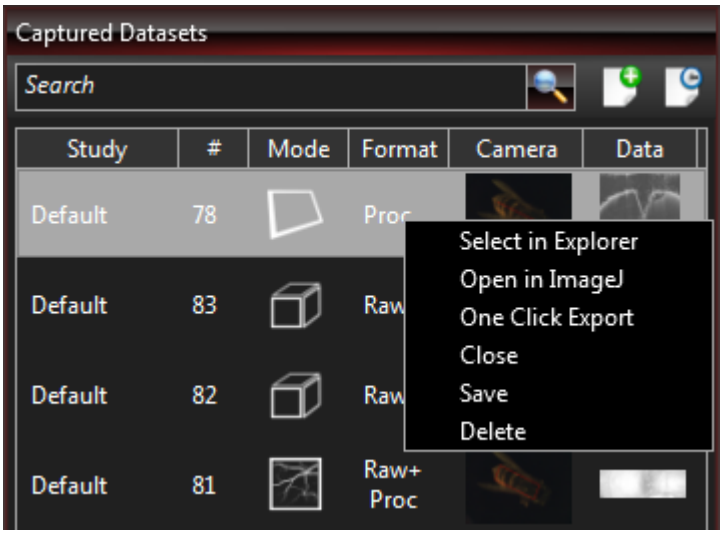


Figure 142 Context Menu in Captured Datasets

3.5.4 Opening Datasets

There are several different ways to open a dataset from disk:

- Click open file in the file menu.
- Press the *Open File* button in the Captured Datasets control.
- Use the *Recent Files* button in the Captured Datasets control.
- Drag and drop a file from the Windows® file explorer into ThorImage®OCT.
- Use the Recent Items feature of the Windows® jump list.

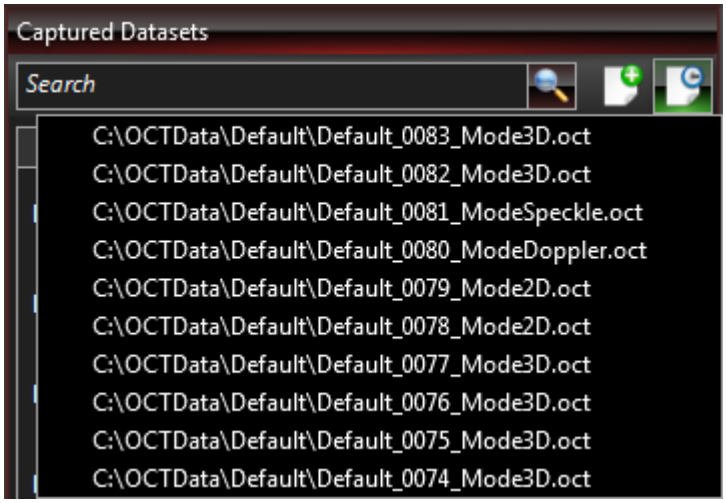


Figure 143 Recent Files List in the Captured Dataset Control

The files neither need to be located in the dataset folder, nor need to have the default file naming scheme in order to be opened in ThorImage®OCT; however, changing the study name is only possible when the file is located in the dataset folder and follows the specified naming scheme.

3.5.5 Changing Datasets

The following parameters can be changed in offline datasets:

- Study
- Refractive Index
- Comment

In 2D datasets, the markers can also be changed. When using the spectral raw data format, processing parameters can be changed in offline datasets as well. An unsaved dataset is indicated in the dataset list with an asterisk (*) after the study name. When closing a dataset which has pending changes, confirmation is required to either save or lose the changes.

3.5.6 Data Export

Captured Datasets can be exported to various file formats using the *Export* buttons in the toolbar. Exported files cannot be reimported into ThorImage®OCT. To load previously saved data, please see the section Opening Datasets.

The options depend on the datasets used in the respective scan mode.

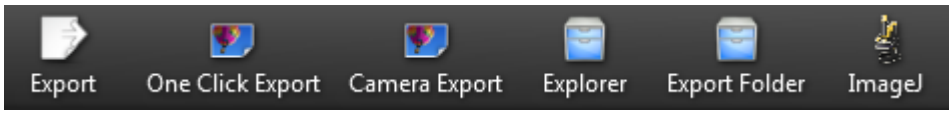


Figure 144 Action Toolbar (Shown Offline)

The default export folder can be changed in the Settings Dialog.

Standard Export

The export button in the toolbar opens a dialog for specifying the export filename and the file format. For 3D data to be stored in image formats, the slice direction and subset of slices to export can be selected. All slices, the currently displayed slice, or a manually specified set of slices can be exported.

Note that depending on mode, acquired data, and export format, not all export options may be available.

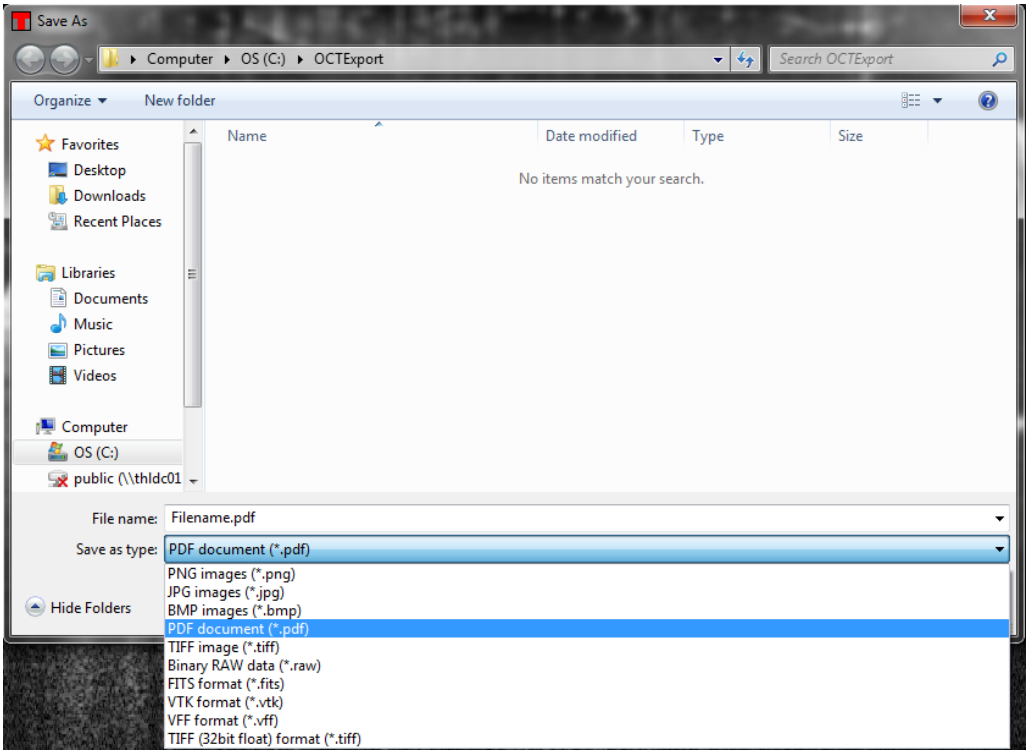


Figure 145 Dialog Window of the Standard Export

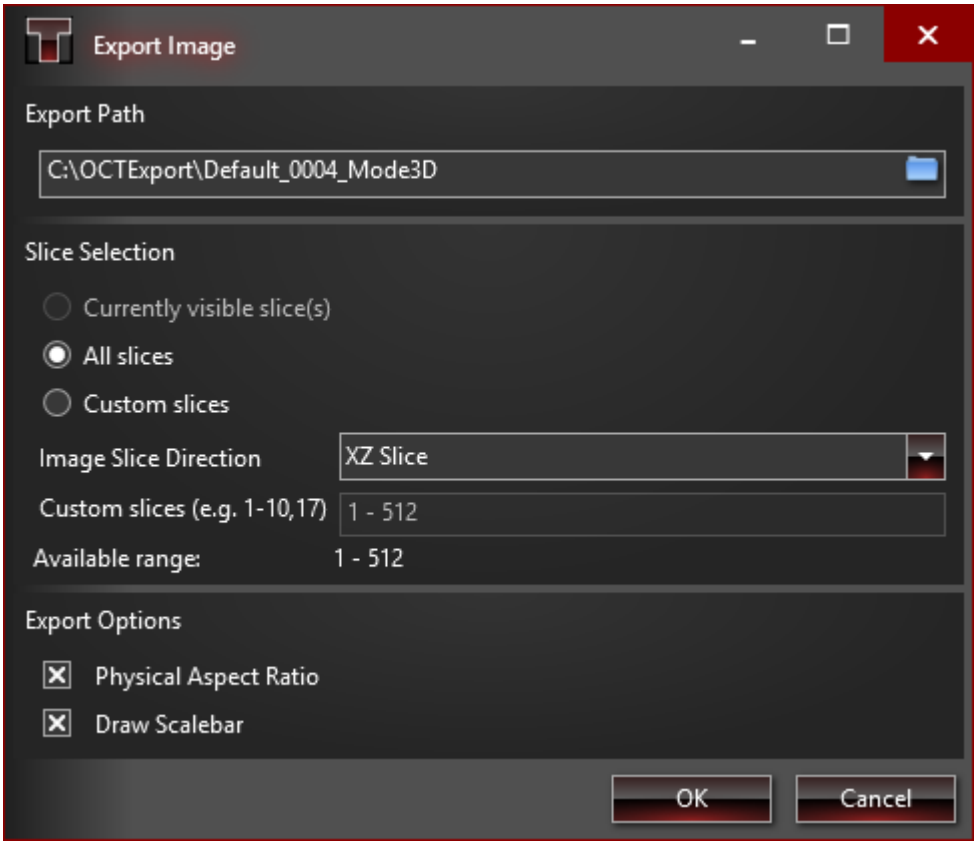


Figure 146 Options when Exporting to Image Formats Using the Standard Export

Quick Export

The *One Click Export* button in the toolbar directly exports the data into the export folder without asking the user for the file format or the filename. Instead, these parameters are globally defined in the settings dialog. When the export is finished, the standard Windows® application for viewing the exported data will be launched (e.g., a PDF reader for PDF files).

Please note that the one click export only supports image file formats. In contrast to the standard export, the one click export stores not only the OCT image but also the sample monitor image.

Camera Export

The currently displayed image of the video camera (Sample Monitor window) can be exported into various image formats using the camera export button.

Export Rendering

Using the *Export Rendering* button when viewing rendered 3D data, a shot of the rendered view can be exported to a .jpg or .png file.

Please note that this button is only visible in the volume view of an offline 3D.

Export Video

For 3D datasets, a video export feature is provided, creating an animated video of the 3D rendering for the current dataset. Supported formats are multipage .TIFF, .GIF, and uncompressed .avi. The following two animation options are available.

- **Rotate Volume Around Z-Axis**
  The video will show a rotation of the volume of 360° around the z-axis.
- **Fly Through Volume**
  The clip plane will be activated and will move through the volume and back once. It is possible to use both export options, in which case the two parts of the video will play in a row, rotation first and then fly through.
  Please note that this button is only visible in the volume.

Figure 147 Options Available for Video Export

Export Surface

For 3D datasets, the surface data of the volume (see section Surface View) can be exported. For each depth sample in the volume, the intensity peak is calculated with sub-pixel accuracy. The resulting 32-bit float data can be exported as any of the supported non-raw data formats.

Please note that this button is only visible in the volume view of an offline 3D data set. Any filters applied to theSurface View are not exported.

Image Formats

ThorImage®OCT supports PNG, JPG, BMP, PDF, and TIFF as image export formats. The coloring in the exported images will be the same as shown in the current dataset display. Slices of temporal 2D or 3D data are stored in a single file for the TIFF and the PDF file format. For the other image formats, each slice will be stored into a separate file and the slice number will be encoded in the filename.

By default, a scale bar is shown in the lower right corner of the exported image indicating the physical size of the image. Furthermore, for 2D datasets, the markers, if any, are shown in the exported images. Both scale bar and markers can be toggled in either the export dialog for the standard export or the settings dialog for the one click export.

During image export, there is the option to maintain the physical aspect ratio. Note that when this option is checked, no downsampling will be performed, i.e. the images might be larger.

Data Formats

Supported data export formats are RAW/SRM, FITS, VTK, VFF, and TIFF (32-bit float). For all these formats, the uncolored OCT data is exported in a lossless fashion as 32-bit floating point data. Note, however, that the scan metadata, e.g. the study name, is only stored in the native OCT file format.

- **RAW/SRM**
  When selecting the RAW export format, two files will be generated: A raw file that contains a little-endian binary stream of the 32-bit processed floating point data, and an SRM file, which is a human-readable and contains information about the dimensions of this binary stream.
- **CRAW**
  When selecting the CRAW export format, a file containing the complex data will be created. The file contains the complex values in a binary stream of little-endian 32-bit processed floating point data. Real and Imaginary files are written in interleaved format, i.e. after each real part, the corresponding imaginary part is stored. Consequently, for each pixel, two values are stored. Please note, the CRAW format is only available for dataset that store unprocessed raw data (see section Dataset Folder and Export Folder). Additionally, in some modes and with some processing options, only intermediate results will be exported in this format.
- **FITS**
  Flexible Image Transport System (FITS) File Format
- **VTK**
  Visualization Toolkit (VTK) File Format
- **VFF**
  Sun TAAC Graphic File Format (also Known as Sun IFF)
- **TIFF (32-bit Float)**
  When selecting the TIFF (32-bit float) format, the data is stored in a TIFF format that supports 32-bit uncolored floating point data. Note that this file cannot be opened correctly by many image viewers (e.g. GIMP).
- **TXT**
  Text File Format
- **CSV**
  Comma Separated Values File Format

Please note that scale bar and markers will only be exported for images, but not data formats.

3.5.7 File Format

Version 4.0 of this software package introduced a new, flexible file format, which remains in use in version 5.x. Its file extension is .oct and it is a zip container (compressed folder) which can be accessed by changing the file extension to .zip and opening the file with a zip viewer such as Windows® explorer.

An OCT file contains an XML file named header.xml which contains metadata describing the captured dataset, e.g. study name, scan pattern and the processing parameters are stored in the Header.xml file.

For all imaging modes, the actual data is stored in a folder named *data*, which contains the following files:

- VideoImage.data: The image of the sample monitor as 32-bit BGRA data stream.
- PreviewImage.data: The preview picture of the data as a 32-bit BGRA data stream (as displayed in the Captured Dataset list).

When using the Store Processed Data option in the settings dialog, the reconstructed OCT data is stored as a stream of uncolored 32-bit (single-precision) floating point data in little-endian byte order. File sizes can be read from the Header.xml file in the root folder of the ZIP container.

Depending on the imaging mode, the following files are stored in the OCT file:

- **2D and 3D Acquisition**
  One file Intensity.data, containing the intensity values in decibel (dB).
- **Doppler Acquisition Mode**
  Two files Intensity.data and Phase.data, containing the intensity in decibel (dB) and phase values, respectively.
- **Speckle Variance Mode**
  Two files Intensity.data and Variance.data, containing the intensity values in decibel (dB) and the variance values, respectively.
- **PS Mode**
  Two files Complex.data and Complex_Cam1.data, containing the complex output of the two processings (one for each camera of the system).

When using the Store Spectral Raw Data option in the settings dialog, the spectral raw data is stored in the data folder in files named Spectral*.data, where * indicates the running number of the B-Scan. Besides the actual spectral raw data, several calibration files required for reprocessing the dataset are also stored in the OCT file.

- **OffsetErrors.data**
  The spectrum used to remove the offset errors from the camera.
- **Chirp.data**
  The vector used to linearize the data from λ- to k-space.
- **ApodizationSpectrum.data**
  The mean of the apodization spectra used for apodization (offset errors already removed).
- **Probe.ini**
  The used configuration file from the probe.

3.5.8 Third Party Applications

An example on how to import Spectral*.data files from an OCT file is given in the MATLAB® script "OCTFileGetRawData.m" found in the *SpectralRadar\Matlab* folder.

Please note that the Header.xml file inside an OCT file contains all necessary metadata to import the spectral raw data with third-party software, e.g. SpectrometerElements and BytesPerPixel information and the exact dimensions of the data in pixels and mm.

The following instruction can be used to import the data with ImageJ:

1. Rename the .oct file to .zip or extract the files directly with any file archiving tool able to handle ZIP compressed files.
2. Open the header.xml file and extract the dimensions of the scan (e.g.: <DataFileType="Raw" SizeZ="2048" SizeX="553" SizeY="1" RangeZ="5.12" RangeX="4.06399" RangeY="1" BytesPerPixel="2" ApoRegionStart0="0" ApoRegionEnd0="25" ScanRegionStart0="25" ScanRegionEnd0="553">data\Spectral0.data</DataFile>)
3. Open ImageJ and import the raw data in the Spectral0.data from the "data" folder ImageJ → File → Import → raw with the following settings:
   a. Image-Type: (BytesPerPixel*8)-Bit Unsigned (from the Above Example: 16-Bit Unsigned)
   b. Width: 2048; Height e.g. 553
      Offset to First Image: 0 Number of Images: e.g. 1 Gap Between Images: 0
   c. Little-Endian Byte Order Checked

The ThorImage®OCT offers built-in functionality to open the acquired datasets automatically using third-party software. The corresponding options are provided in the Action Toolbar when viewing a captured dataset.

Thorlabs does not provide support for third party software.

Explorer

The *Explorer* button opens the Microsoft® Windows Explorer at the location where the currently selected dataset is stored.

ImageJ

The *ImageJ* button opens the currently viewed dataset with ImageJ. For this option to be available, the ImageJ path needs to be set in the settings dialog. The ImageJ distribution Fiji comes preinstalled on the OCT system's computer but can also be manually installed from the OCT software DVD.

(Thorlabs does not provide support for third party software. For more information about ImageJ and Fiji, please visit http://imagej.nih.gov/ij/index.html and http://fiji.sc/Fiji.)

External Programs

This feature allows datasets to be opened by user-specified third-party applications. Clicking the *External Programs* button will open a drop-down menu showing a list of external programs to open the dataset.

To create an external program specification, see the section External Programs.

3.6 Dataset Parameters

This section describes the options in the Dataset Parameters control which are common to all acquisition modes.

In data viewing mode, most of these parameters are disabled (i.e. grayed out) and represent their state in the currently displayed dataset. Some parameters, such as comment or refractive index, can be further modified; these changes can be saved when closing the respective dataset.

The following parameters can be adjusted:

- General
- Comment
- Scan Pattern
- Averaging
- Device Presets
- Device Settings
- Analog Measurements[a]
- Trigger I/O[a]
- Recording
- Processing
- Device Info

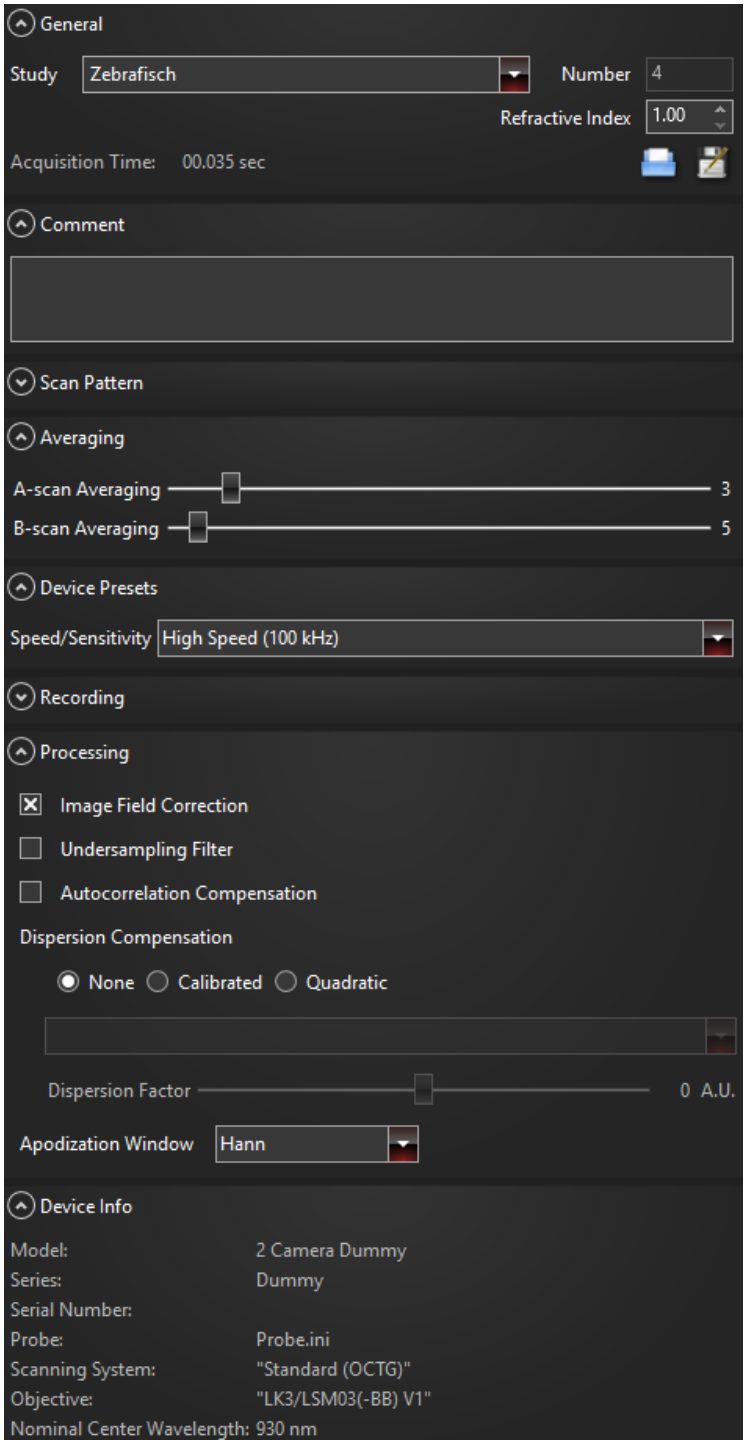


Figure 148 General Dataset Parameters

a. Requires hardware-support from the OCT device; entry is only displayed if functionality is supported.

3.6.1 General

The general section of the dataset parameters contains information used to identify the dataset and options specific to the current measurement. A study is intended to comprise one or more datasets in the same scope and is freely editable. Each additional measurement will cause the (Experiment) number field to be automatically incremented, thus each measurement / experiment is uniquely identified by study name and number.

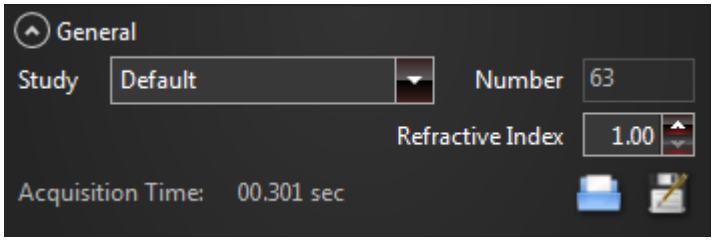


Figure 149 General Panel

Fields in the general section are used to uniquely identify each dataset. Additional options that are specific to the sample can be set here.

Study
User defined name to identify the current set of measurements. For each study, several measurements can be performed where each scan is identified by a unique Experiment Number.

The study name determines the storage location for the dataset (see section Dataset Location).

Experiment Number
The running number uniquely specifies the measurement in the current study. The Experiment Number is determined automatically by ThorImage®OCT and cannot be assigned manually.

Refractive Index
For each measurement, a refractive index of the sample can be specified. The physical axial depth of the image will be scaled by the inverse of the refractive index. The refractive index can also be modified for already stored measurements. It influences the measurements made with the marker tool.

Acquisition Time
This label shows the acquisition time per single scan. For 2D and Doppler Acquisition Modes, the acquisition time is calculated for a single B-Scan, whereas for 3D and speckle variance modes, the time for a single volume/variance scan will be shown.

Load/Save Dataset Parameters
Using the *Save Dataset Parameters* button, the currently set dataset parameters can be stored to a file. Please note that this parameter file contains the dataset parameters for all imaging modes. The dataset parameters can be restored by using the *Load Dataset Parameters* button and selecting a stored parameter file.

3.6.2 Comment

The comment field is an optional text field that can be used to add a descriptive text to each dataset. The comment field can be modified and will be saved in the currently displayed dataset's OCT file.

Figure 150 Comment Panel

The comment panel can be used to store additional information and user specified metadata that is specific for a dataset.

3.6.3 Scan Pattern

The scan pattern is the geometrical region sampled during a measurement.

The simplest scan pattern for a B-Scan is a rectilinear line segment. A sequence of B-Scans along a third direction is a volume. These simple geometries are the starting point of many experiments, and are grouped here under the name "standard" scan patterns.

Sometimes the region of interest is not exactly rectangular, or a rectangular construction would lead to extremely bulky datasets, forcing the whole experiment to slow down (not always acceptable). In these cases, an ad-hoc geometry should be drawn. These patterns are grouped here under the name "freeform" scan patterns.

In order to specify a scan pattern, please refer to the 1D Acquisition, 2D Acquisition, or 3D Acquisition scan pattern sections in this user guide.

3.6.4 Averaging

The ThorImage®OCT comes with averaging options that provide trade-offs between imaging speed, imaging quality, and sensitivity. Different processing options show different vulnerabilities to motion-induced imaging artifacts. The averaging options available depend on the active imaging mode.

The Averaging parameters to be used in OCT processing should be set in the acquisition modes. Available parameters might vary depending on the operating mode.

Figure 151 Averaging Parameters

A-Scan Averaging
A-Scan averaging improves the imaging quality by flattening the noise floor and increasing the sensitivity at the cost of slower acquisition. Sample motion does not result in phase washout or blurring of the images; the signal remains intact, however motion can induce distortions within the acquired data.

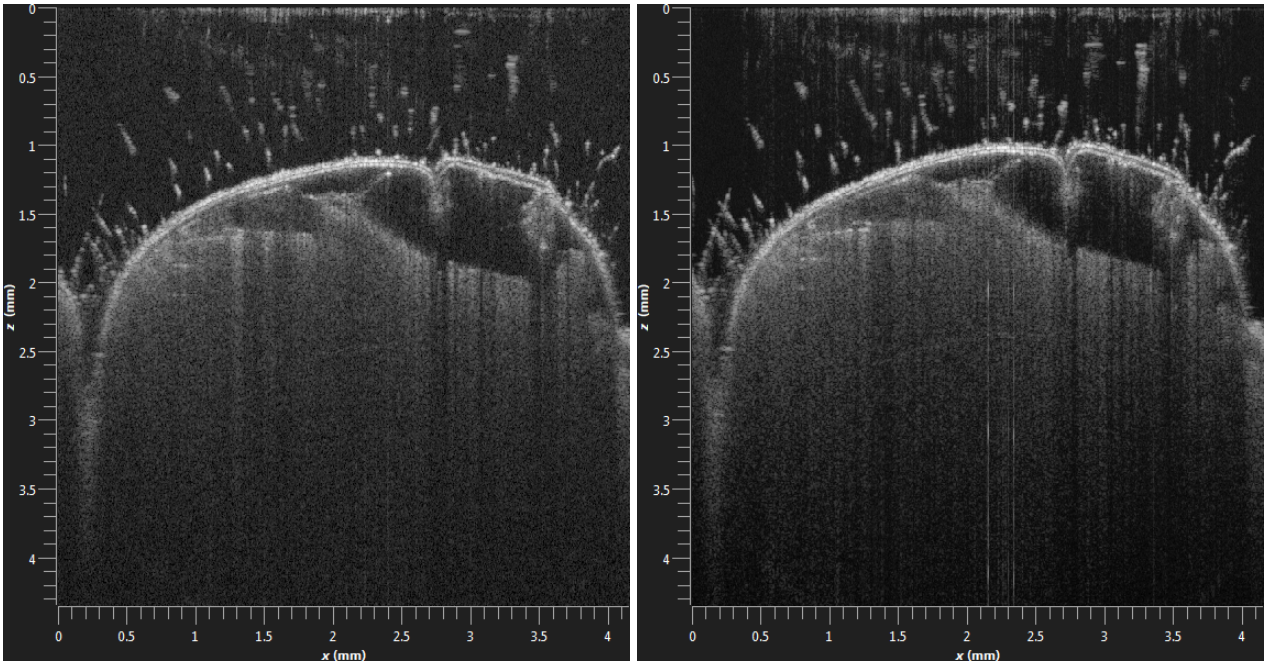


Figure 152 (Left) B-Scan of a Bug (No Averaging Applied)
Figure 153 (Right) A-Scan of a Bug with Averaging and Slight Motion (No Artifacts Occur)

B-Scan Averaging

B-Scan averaging improves the imaging quality by flattening the noise floor at the cost of slower acquisition. The computation is done by a moving average so that the update rate on screen remains intact. B-Scan averaging can in some situations produce better images, but creates artifacts if sample motion is present. If motion artifacts are a limiting factor when using B-Scan averaging, consider using the *Advanced Snapshot* button.

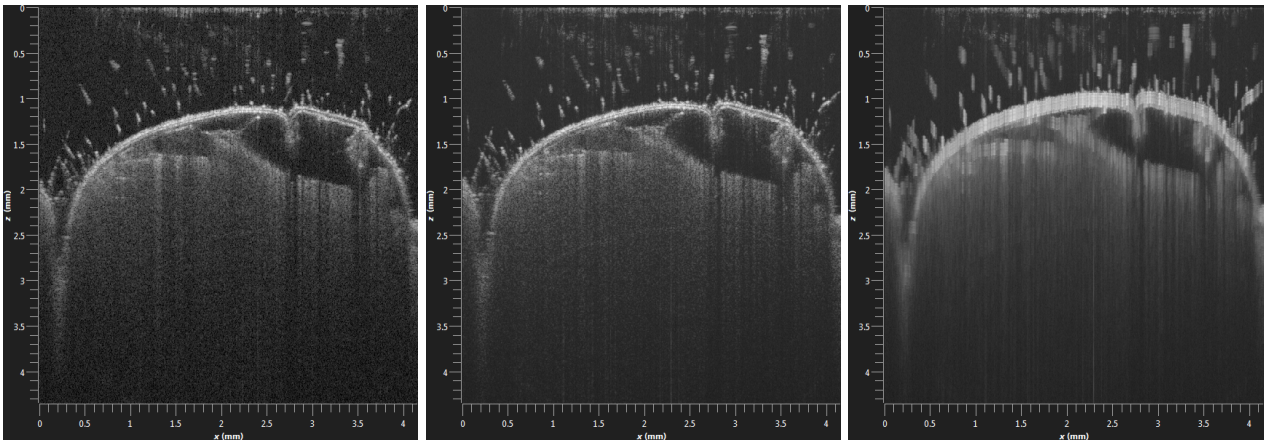


Figure 154 (Left) B-Scan of a Bug With no Averaging Applied
Figure 155 (Middle) B-Scan Averaging of a Bug (Same Sample)
Figure 156 (Right) B-Scan Averaging and Slight Motion Resulting in Imaging Artifacts (Same Sample)

B-Scan averaging is not available when using the spectral raw data format. However, similar images can be achieved by using the Advanced Snapshot.

Spatial Averaging

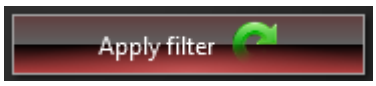
In polarization-sensitive modes it is possible to average pixels in a rectangular neighborhood around each one. It is not a Gaussian filter, but the net effect is similar to the blur image option, except that the extension of the averaging can be selected.

Figure 157 For two-dimensional measurements it is possible to select averaging along the z and x directions, and also between consecutive frames.

Figure 158 In three-dimensional measurements it is possible to filter along the axes z (depth), x, and y.

Frame averaging is only possible when enough consecutive frames are available for computation. This is the case in live-measurements, and also in multi-frame datasets read from files.

Filtering involves recomputing nearly all data, making it a time-consuming process. Therefore, filters are not applied immediately to offline data. Instead, the user sets the desired filter levels and then clicks the *Apply Filter* button (to compute the filtered data).



Figur 159 Apply Filter Button

Spatial averaging affects retardation, optic axis, and the Stokes parameters. It neither affects the intensities nor the DOPU.

3.6.5 Device Presets

Certain devices offer presets that alter the behavior of the system. The actual available presets thereby differ from system to system. Most commonly, devices offer the following presets.

Speed/Sensitivity

The Ganymede and Telesto OCT series feature speed preset switching. The Speed/Sensitivity drop-down list provides different presets affecting the spectrometer inside the OCT engine. These presets usually change the spectrometer's acquisition rate and consequently the integration time and the sensitivity. As a rule of thumb, the lower the acquisition frequency, the higher the sensitivity. Changing a preset also changes acquisition time as indicated in the section General.

Figure 160 Device Presets Panel

Some systems offer options for the acquisition rate and the sensitivity.

If the speed/sensitivity settings are changed, the reference intensity needs to be adjusted to allow for optimal imaging (see section Reference Intensity (SD-OCT Only).

3.6.6 Device Settings

The entries in this section depend on the hardware currently available. ThorImage®OCT offers only those options actually available. If no hardware-settings option is available in the installed system, this section does not appear.

Active Sensors

This settings-option appears in systems equipped with more than one sensor. Depending on the activated mode, it may happen that all sensors are used, or only one (the selected). The figure below depicts the two situations:

Figure 161 This mode utilizes all sensors,including polarization-sensitive ones.

Figure 162 This mode uses a single sensor. The user can choose the active sensor from the list.

Whether the mode uses all sensors or only one of them is a property of the mode and cannot be changed by the user.

If the user acquires and stores data, this option will also be written to the file, and will be displayed again whenever the file is loaded.

Polarization Adjustment (VEG200 & ATR200 Series Only)

To achieve the best possible OCT image quality, the polarization state of the reference light and the light from the sample should match. Devices from the VEG200 and ATR200 series are equipped with two motorized fiber polarization adjusters to accomplish this. These adjusters work by bending the fiber carrying the reference light, which changes the polarization state and angle of the light.

Figure 163 Polarization Adjustments Window

These controls are accessible in all acquisition modes via the Dataset Parameters panel located on the right side of the screen, under the Device Settings category.

Generally, if the sample has been altered or the probe repositioned, adjust the polarization controllers until the artifacts in the OCT image are minimized.

Sampling Dynamics Adjustment

- The Amplification Level slider controls the analog amplification of the electrical OCT signal before it is sampled by the analog-to-digital converter. In general, it should be set as low as possible (without causing the interference-amplitude to diminish too much) to achieve the best signal-to-noise ratio.
- The Reference Intensity attenuates the amount of reference light that will reach the sensor. In general, it should be set as high possible (without causing oversaturation).

3.6.7 Analog Measurements

Some Thorlabs OCT devices support acquisition of analog signals during OCT imaging. These devices offer one or more analog input connectors at the back of the device.

For each A-Scan in the OCT-Scan the device will take one sample of the analog voltage of each channel. Each A-Scan represents an array of depth samples while the analog sample consists of a single value. Therefore, the analog data always has one less dimension than the OCT data, i.e. a 2D OCT-Scan contains a 1D analog dataset and a 3D-Scan contains a 2D analog image.

The channels to be sampled can be selected from the Analog Measurements panel:

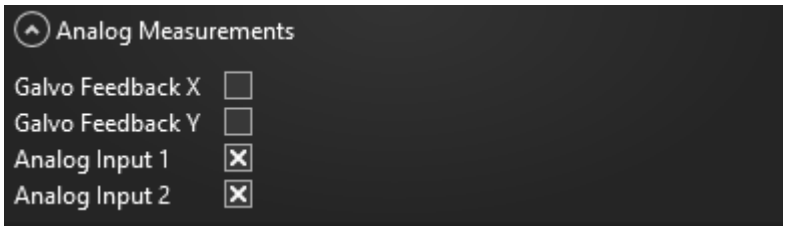


Figure 164 Analog Measurements

If no channels are selected, analog measurement is disabled.

Current devices support a selection of two out of four channels. *Analog Input 1* and *Analog Input 2* map to the respective input connectors at the back of the OCT base unit (see the corresponding OCT hardware user guide).
Galvo Feedback X and *Galvo Feedback Y* are hardwired to capture the feedback signal from the galvanometer scanners.

Whenever an OCT dataset is captured with at least one analog channel enabled, the resulting OCT file will contain the captured analog data. When viewing the OCT file, the Analog Measurements panel will be displayed in the window Dataset Parameters:

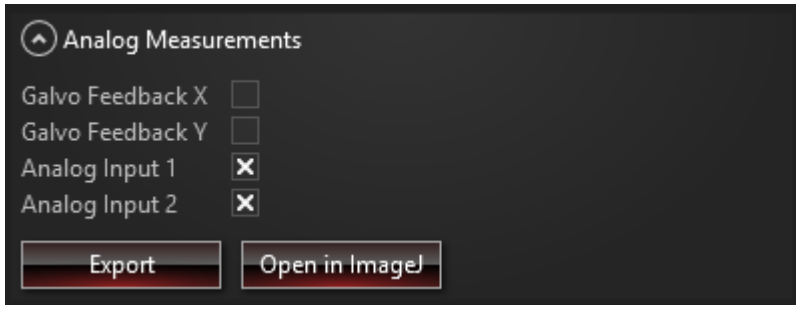


Figure 165 Analog Measurements with Information for a Loaded OCT File

The channel selection list for an OCT file in data viewing mode is for informational purpose only and thus cannot be edited.

The *Export* button allows raw data export in a number of different formats. The data may then be analyzed or processed in third-party software tools.

The *Open in ImageJ* button will open the analog dataset in the ImageJ editor. The data will automatically be split into an image stack with one layer per channel. From ImageJ the data can then easily be exported or converted in an even more flexible manner.

Additionally, captured analog data can be visualized in 3D acquisition. For details see the section Analog Measurement Data Visualization.

3.6.8 Trigger I/O

Some Thorlabs OCT devices offer a secondary trigger channel, in addition to the primary A-Scan trigger. This Trigger I/O channel can be flexibly configured to act in multiple ways, for example as a B-Scan or volume trigger and in input and output mode. On supported devices, the Trigger I/O configuration panel will be displayed in the Dataset Parameters during acquisition:

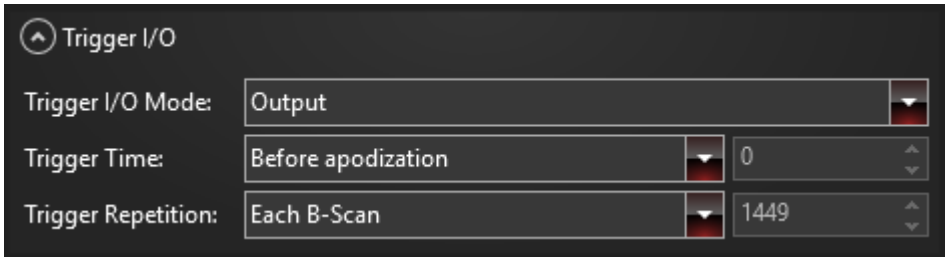


Figure 166 Trigger I/O Configuration Panel

The timing of the Trigger I/O pulses is tightly linked to the internal workings of the OCT-Scan patterns. An OCT-Scan consists of several regions which are described in detail in the section Anatomy of an OCT-Scan.

Trigger I/O Mode
The Trigger I/O can operate in two active modes (or be disabled): it can act as either an input, responding to external signals or an output, generating trigger signals.

When the Trigger I/O is operating in input mode, it behaves similar to the external A-Scan trigger (see also section External Triggering): once an acquisition is started, the device will wait until a trigger signal is received on the I/O line. It will then perform a number of A-Scans. Depending on the configuration, the system may capture a single A-Scan, a B-Scan, a full volume scan or anything in between.

In Output mode, the system will start scanning as soon as the acquisition is started (or with the first A-Scan trigger, if external A-Scan triggering is used). The Trigger I/O line will periodically generate output pulses while the acquisition is running. The timing of these pulses also depends on the configuration.

Please note that if the external A-Scan trigger is enabled, the Trigger I/O can only be used in output mode.

Trigger Time
This setting can only be adjusted in output mode. This parameter determines at which point in an OCT-Scan the first trigger I/O signal is generated. The following options are available:

- **Before Apodization**
  The trigger signal is generated immediately at the start of the scan, at the first A-Scan of the apodization region which comes before the imaging region.
- **Before Scan**
  The trigger signal is generated at the first A-Scan of the imaging region of the scan.
- **After Scan**
  The trigger signal is generated at the first A-Scan after the imaging region of the scan.
- **Custom**
  An arbitrary number n can be entered. The system will repeat the trigger I/O signal after each n A-

Scans, i.e. $n = 0$ is not allowed, $n = 1$ means there will be a Trigger I/O pulse for every A-Scan, $n = 2$ that there will be a pulse on every second A-Scan and so on.

Trigger Repetition
This setting can be adjusted in both Input and Output mode, but the meaning is slightly different in each case. In "Output" mode, this setting determines at which interval the trigger I/O signal repeats. In "Input" mode, this setting determines how many A-Scans will be performed for each pulse received on the trigger I/O line.

In B-Scan mode, the first two options of this setting are functionally identical. The following settings are available:

- **Each B-Scan**
  The trigger signal repeats with every B-Scan of the full scan, i.e. it works as a line trigger in volume mode.
- **Each Full Image**
  The trigger signal repeats with every full scan, i.e. it works as a volume trigger in volume mode.
- **Custom**
  An arbitrary number n can be entered. The system will repeat the trigger I/O signal after each n A-Scans, i.e. $n = 0$ is not allowed, $n = 1$ means there will be a Trigger I/O pulse for every A-Scan, $n = 2$ that there will be a pulse on every second A-Scan and so.

3.6.9 External Triggering

Many Thorlabs OCT devices may use an external trigger signal to synchronize A-Scan acquisition to external processes. On supported devices, the external A-Scan trigger may be enabled in the section Hardware.

When external triggering is enabled, the device will no longer generate its own timing signals. Instead, once the acquisition is started, the device will wait for external trigger pulses and perform a single A-Scan on each received trigger. This is functionally related to the Trigger I/O.

By activating the external trigger mode, a new tab will appear in the window Dataset Parameters. All parameters, except for the Trigger Timeout, are read-only and depend on the imaging sensitivity, speed, and scan pattern.

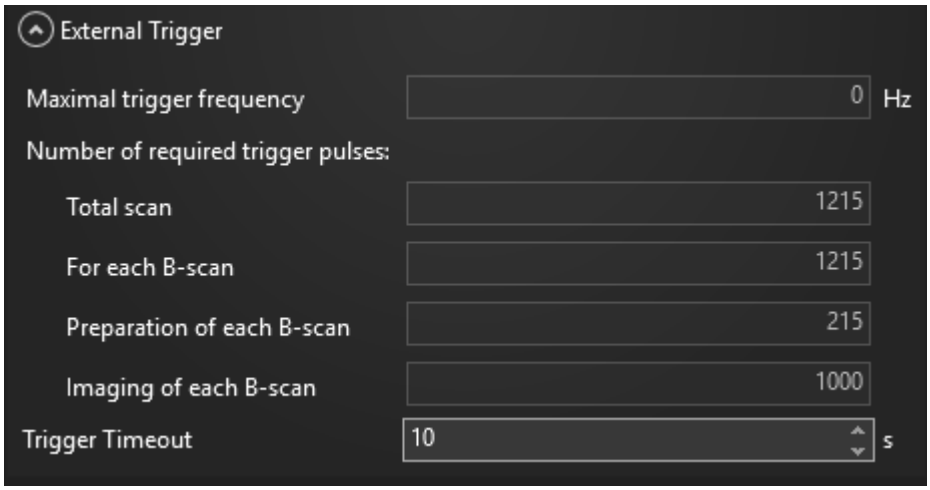


Figure 167 External Trigger Configuration Tab

Maximum Trigger Frequency
This field displays the maximum valid frequency for the trigger signal. If the used frequency is higher, the behavior of the camera cannot be predicted and may cause errors. This parameter depends on the chosen Averaging/Device Presets.

Number of Required Trigger Pulses
The parameters depend on the set imaging speed, sensitivity, averaging parameter, flyback time, and the sizes of the scan pattern and apodization. Please note that the flyback time and apodization scan count are part of the probe configuration and are typically factory presets.

Total Scan
The number of trigger pulses required for one scan. In 2D acquisition this is for one B-Scan, in the volume mode this will be the number of scans for the whole volume.

Preparation of First B-Scan
If a fast volume pattern is used, this is the number of trigger pulses to be sent before the first B-Scan commences. In all other cases, this will be zero.

For Each B-Scan
The number of trigger pulses for a single B-Scan which consists out of the preparation region followed by the scan region.

Preparation of Each B-Scan
The number of trigger pulses required for the preparation region. This is the first part of each B-Scan pattern.

Imaging of Each B-Scan
The imaging scans are the last scan points in each B-Scan pattern. This number is equal to Size X in Scan Pattern.

Trigger Timeout
After starting the measurement, the software is waiting for a trigger signal to occur or will stop the measurement after the given timeout. It is necessary to stop the actual measurement before starting a new one.

All changes of parameters will stop/start the measurement, and therefore it is important that no trigger signal is sent during the initialization of the acquisition.

If the SpectralRadar SDK and the external trigger mode is used, please ensure that the trigger signal starts after startMeasurement() and ends after stopMeasurement(). The ExternalTriggerDemo() function in the C++ Demo shows an example for the timing to start and stop the trigger signal.

For correct operation of the External Trigger Mode, it is crucial to supply the system with a valid trigger signal. It is important that the signal on the base unit and the PC is on low when the measurement is started on the PC. Sending a trigger signal while the following message is visible can lead to a misalignment of the preparation and scan regions.

The preparation of the acqusition is running. Trigger signals received while this message is being displayed can cause timing issues.

Figure 168 Displayed Message while Preparation of the Acqusition

3.6.10 Recording

In the recording options, one can specify the number of B-Scans that are recorded when pressing the *Record* button in the Action Toolbar. By default, the number of recorded frames is not limited. When selecting the *Stop recording after* check-box, one can specify the number of frames that are recorded.

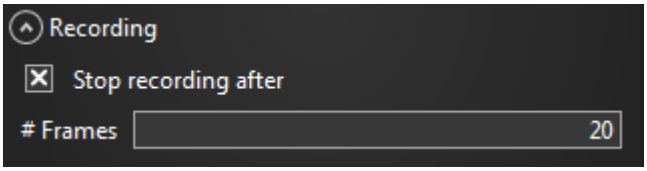
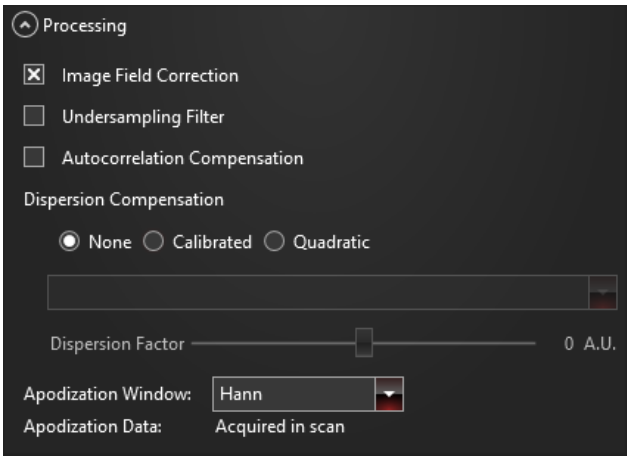


Figure 169 Stop Recording after Check-Box

The *Stop recording after* check-box can be set to automatically stop after a predefined number of frames.

3.6.11 Processing

The ThorImage®OCT offers various processing options that can enhance imaging quality, albeit at the expense of processing speed. These parameters can be configured either before or during data acquisition (in 2D Acquisition and Doppler Acquisition Mode). Additionally, when using the spectral raw data format, it is possible to reprocess the data offline. The *Reprocess Data* button is disabled when the currently displayed OCT data has been processed with the currently shown processing parameters.



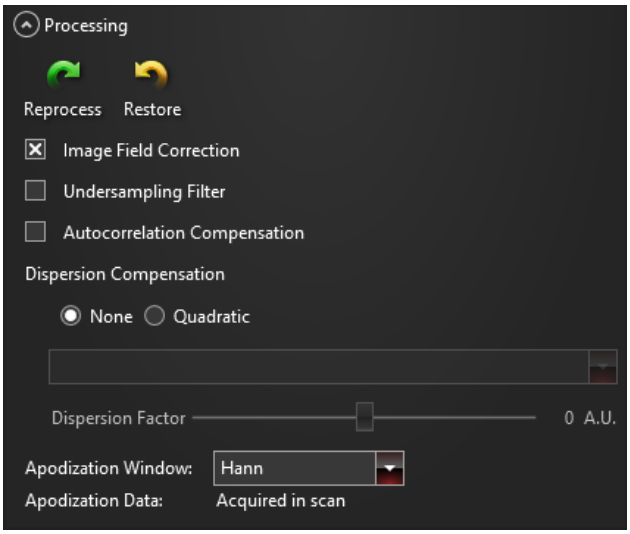


Figure 170 (Left) Processing Parameters that Can Be Set in Different Imaging Modes
Figure 171 (Right) Processing Parameters that Can Be Reprocessed in Offline Mode

Image Field Correction

When acquiring large image fields, an offset to the optical path length of the sample arm might occur, depending on the lateral scan position. As a result, a flat surface can appear to be curved. Image field correction provides a numerical correction for this and corrects the geometry of the surface by using calibrated factors.

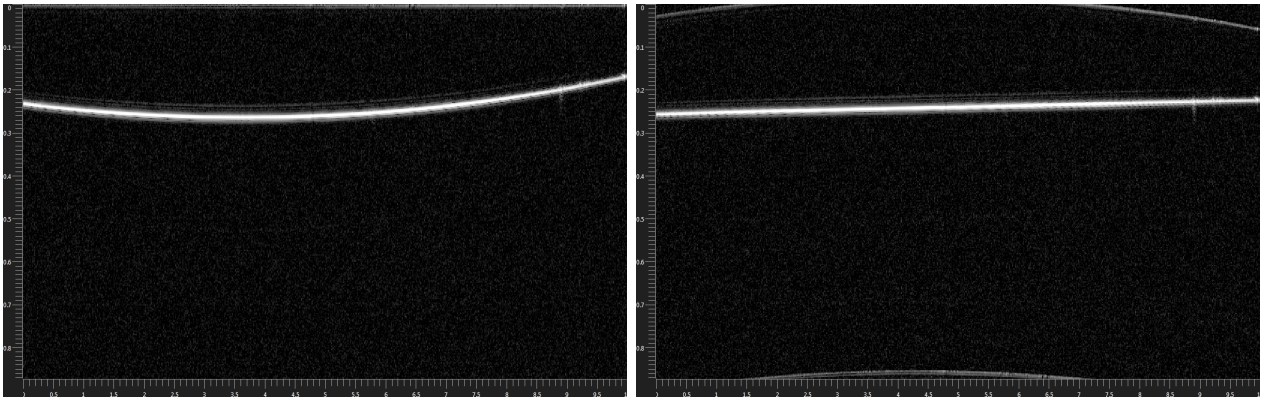


Figure 172 (Left) B-Scan with Image Field Distortion Visible
Figure 173 (Right) B-Scan with Image Field Correction Enabled

Please note that processing speed may suffer when the image field correction is activated.

The image field correction is not available in the 1D acquisition.

Undersampling Filter

Scatterers and reflecting surfaces that are positioned close to the largest possible measurement depth might show aliasing artifacts. These artifacts can partially be compensated by activating the undersampling filter.

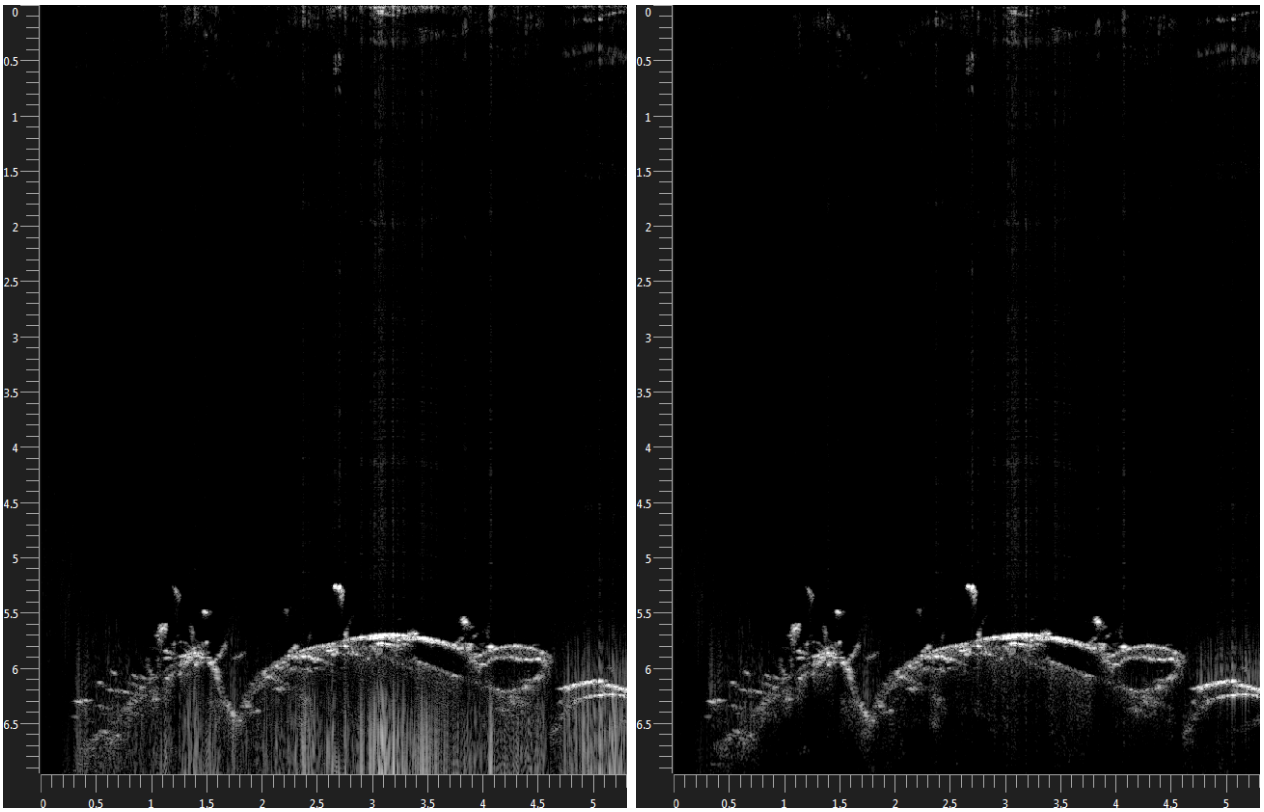


Figure 174 (Left) B-Scan With Visible Aliasing Artifacts
Figure 175 (Right) B-Scan With Undersampling Filter Enabled

Please note that processing speed may suffer when the undersampling filter is activated.

Autocorrelation Compensation

At low acquisition speed, the standard Fourier reconstruction technique can suffer from autocorrelation artifacts that are due to interference of the sample light with itself. These artifacts can partially be reduced by activating the autocorrelation compensation.

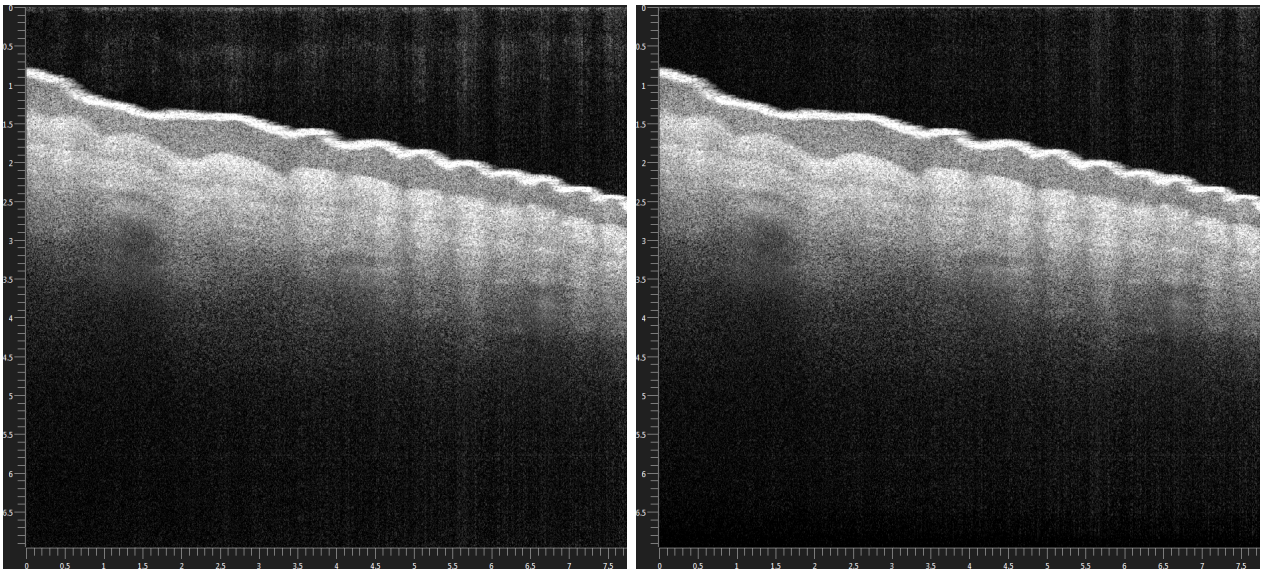


Figure 176 (Left) B-Scan With Autocorrelation Artifacts

Figure 177 (Right) B-Scan With Autocorrelation Compensation Enabled

Please note that processing speed may suffer when the autocorrelation compensation is activated.

Dispersion Compensation

In general, group velocity dispersion mismatch between sample arm and reference arm causes axial blurring of the acquired signals, as the optical path length differences vary with the wavelength. Using the dispersion correction settings of the ThorImage®OCT, the effects of dispersion mismatch can be reduced. Commonly, dispersion mismatch is introduced either by the imaging probe or by the sample, e.g. when imaging through several millimeters of water.

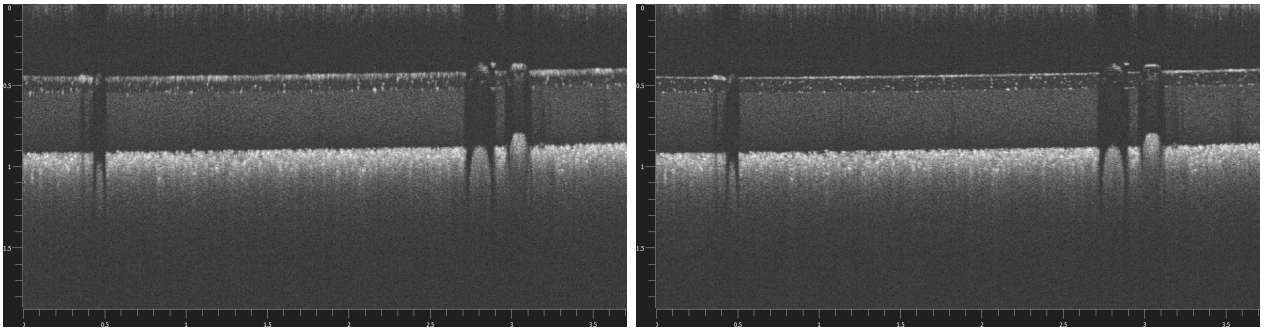


Figure 178 (Left) B-Scan With Visible Blurring Due to Dispersion in the Sample Arm

Figure 179 (Right) B-Scan With Dispersion Compensation Enabled

- **Calibrated Dispersion Compensation**
  For static dispersion, as created by the imaging probe, a calibrated dispersion vector can be used. This does not work for correcting dispersion that is introduced by the sample. Please note that the controls for selecting calibrated dispersion compensation presets are only shown when calibration data is available.

- **Quadratic Dispersion Compensation**
  Using the quadratic dispersion compensation and moving the dispersion slider, the user is able to correct the exact amount of dispersion present in the images.

Please note that the processing speed may suffer when the dispersion compensation is activated.

Apodization Window
In the processing of the OCT data, spectral shaping is applied. By selecting a suitable apodization window, a compromise between axial FWHM resolution and side-lobes is achieved. In general, the Hann window yields good and artifact-free imaging quality. For high-resolution (small FWHM) imaging, the tapered cosine window can be used at the cost of increased imaging artifacts, especially from high signal-to-noise ratio of reflecting surfaces.

Apodization Data
Each OCT scan needs an apodization vector to transform the raw spectrum into a depth scan. This vector can have different sources. If an acquisitionmode is currently active, this field indicates how the apodization vector will be acquired. If an offline dataset is currently opened, this field indicates how the apodization vector in the dataset was acquired.

This field may have the following values:

- **Unknown**
  Source was not stored in OCT file (file was recorded with ThorImage <5.8).
- **None**
  No apodization vector was used (this is the case for data acquired with swept source OCT systems).
- **Acquired in Scan**
  Apodization vector was measured during the scan (default for spectral domain OCT systems).
- **Measured**
  Apodization vector was measured individually before the scan.
- **Derived from OCT Data**
  Apodization vector was not measured, but calculated from OCT data.

3.6.12 Device Info

The Device Info section shows information about the device and probe that are in use or that have been used when a dataset was acquired. This is especially useful when working with multiple devices or with different objectives in order to know the device and probe that were used to acquire a specific dataset.

Figure 180 Device Info Section

The Device Info section shows the following details:

- Model (Displaying Engine Type with Article Number)
- Series (Displaying Family Type)
- Serial Number
- Probe & Probe Description (Scanning System with Probe Type)
- Scanning System
- Objective
- Nominal Center Wavelength

3.7 Sample Monitor

The sample monitor tool window displays a live video image of the sample if one of the acquisition modes is selected. The sample monitor provides visual aid in positioning the sample. The focus can be adjusted by focusing the sample in the video image. Additionally, the scan position can be determined in the sample monitor.

If an offline data record is selected, a static video image of the offline data record is displayed.

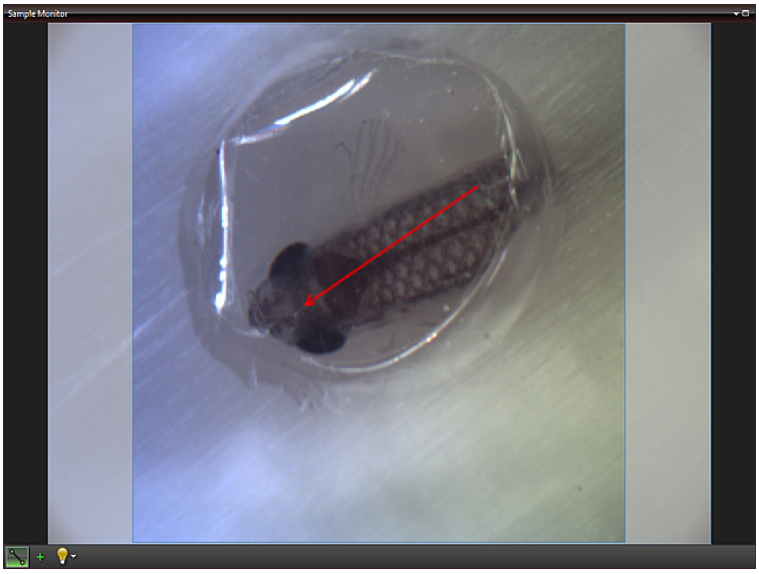


Figure 181 Sample Monitor Showing a Live Image of the Video Camera (Display of Scan Region Is Switched On)

Scan Region/Draw & Scan

The current scan region can be displayed as an overlay on the video image. In 2D acquisition, the overlay appears as an arrow representing the start and end of the B-Scan line. The tip of the arrow indicates the last acquired A-Scan of the B-Scan, corresponding to the rightmost vertical line in the OCT display. In 3D acquisition, a rectangle indicates the area to be scanned, whereas in 1D acquisition, the beam position is indicated by a red cross.

The visibility of the scan region can be toggled on and off using the *Scan Region* button below the video image. The scan region can be directly modified using the Draw & Scan feature, allowing the scan pattern to be drawn directly onto the video image by clicking the start and end points of the scan.

In all modes, the maximum possible scan region is displayed as a blue rectangle, with areas outside the possible scan region overlaid with a gray haze. No part of the scan pattern can extend outside the blue rectangle. For some hardware configurations, the field of view of the video camera may be larger than the maximum possible scan region for OCT imaging, as shown above.

Ring Light

The standard probe included with the Thorlabs SD-OCT systems features a ring light to illuminate the sample for the video image. The intensity of the ring light can be adjusted by clicking the *Ring Light* button and moving the *Control Slider*.

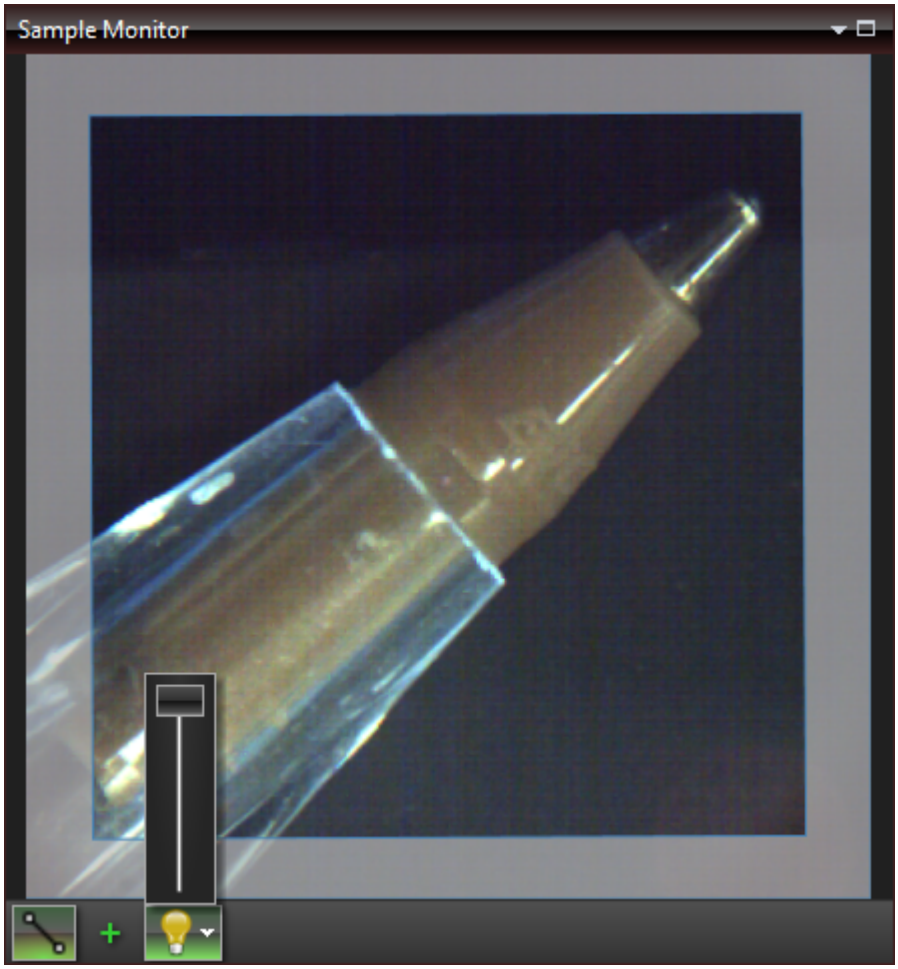


Figure 182 Ring Light Slider in the Sample Monitor Control (Display of Scan Region Is Switched Off)

Please note that the Ring Light and its Control Slider are not available in all OCT systems.

Chapter 4 Software Development Kits (SDKs)

The low level SpectralRadar SDKs offer maximum flexibility whereas ThorImage Automation (TIA) is a high level API to automate functions from ThorImage®OCT within a user-made program. Beside that the user can implement their own OCT processing in Python embedded in the Thorlabs ThorImage®OCT. Additional to this the feature external programs is available for data modification or analysis acquired with the ThorImage®OCT.

		SDKs	ThorImage Automation	Python Processing	External Programs
Entry Point		User Program	User Program	ThorImage® OCT GUI	ThorImage® OCT GUI
Flexibility/Limitation		Great Flexibility	Limited to Specific ThorImage® OCT GUI Functionality	Limited to OCT Processing Functionality	Limited to OCT Post Processing Functionality
Programming Level		Low Level	High Level with Very Little Code	Low Level OCT Processing Only	Low Medium Level Post Processing Only
Inline/Offline		Full Control on User Side	Inline Hook to Specific ThorImage® OCT GUI Functions to the User Code	Inline User Processing Code Used in ThorImage® OCT GUI	Offline Feature in ThorImage® OCT GUI
ThorImage®OCT Running/Usable at the Same Time		×	✓	✓	✓
Programming Language	**C**	✓	✓	×	Arbitrary Third-Party Software
	C#	Via C-API	✓	×	
	LabView	✓	✓	×	
	Python	✓	✓	✓	
Example User Requirements: Implementation of …	**User GUI**	✓	×	×	×
	User OCT-Processing	✓	×	✓	×
	User Post-Processing	✓	×	×	✓
	Automation	✓	✓	×	×
Recommended OCT Knowledge		Advanced	Beginner	Beginner	Beginner
Recommended OCT Processing Knowledge		Beginner	Beginner	Advanced	Beginner

Table 4 Software Development Kits (SDKs)

Please note that all following links contain the default installation path which is used during production on the OCT systems computers. If the software is installed on the user's own computer the installation path might be different.

4.1 SpectralRadar SDKs

For maximum flexibility, the ThorImage®OCT offers several possibilities to implement customized solutions using the software development kits (SDKs). Experienced software developers will be able to use these in a multitude of programming environments to tailor the use of Thorlabs OCT systems to their requirements.

4.1.1 ANSI C

The ANSI C SDK is the core development kit. It allows a user to directly control the Thorlabs OCT Imaging System, implement customized scan patterns and execute processing routines.

- **Documentation and Introduction**
  C:\Program Files\Thorlabs\SpectralRadar\Manual\C Reference.pdf
- **C++ Demo Programs**
  C:\Program Files\Thorlabs\SpectralRadar\C++ Demo
  This folder contains a Microsoft® Visual Studio project with the code for simple and advanced sample programs and already compiled applications.
- **Header File SpectralRadar and SpectralRadar.lib**
  C:\Program Files\Thorlabs\SpectralRadar\include\SpectralRadar.h
  C:\Program Files\Thorlabs\SpectralRadar\lib\SpectralRadar.lib

A customized solution using the ANSI C SDK can have all the functionalities as the ThorImage®OCT, as this software is based on the ANSI C SDK.

4.1.2 LabVIEW™

The LabVIEW™ SDK exposes most of the functionality from the ANSI C SDK in LabVIEW™, including a collection of demo VIs to get the user started in developing customized software solutions.

- **Documentation and Introduction**
  C:\Program Files\Thorlabs\SpectralRadar\Manual\LabVIEW Reference.pdf
- **Demo Programs and SpectralRadar.llb**
  C:\Program Files\Thorlabs\SpectralRadar\LabVIEW

We recommend using the ANSI C SDK documentation for the use of LabVIEW™.

4.1.3 MATLAB®

The MATLAB® SDK contains a collection of scripts for Mathworks MATLAB®. The scripts for Mathworks MATLAB® enable users to open OCT files and read processed as well as raw data files in MATLAB®. It is limited to reading OCT files into MATLAB®.

The more advanced programmer might use the ability of MATLAB® to load a C library and call it directly out of Matlab®. Using this implementation allows full access to ANSI C SDK.

1. Add the ThorImage®OCT installation path and its subfolders to MATLAB® with "Set Path" → "Add with Subfolders ..." within MATLAB® before trying to open OCT files within MATLAB®.
2. The file
   C:\Program Files\Thorlabs\SpectralRadar\Matlab\Examples\Readme.txt
   contains more information how to use the MATLAB® scripts which are located in the folder
   C:\Program Files\Thorlabs\SpectralRadar\Matlab.

3. The script
   C:\Program Files\Thorlabs\SpectralRadar\Matlab\Examples\LoadOCTFile.m
   provides an entry point to the MATLAB® scripts. There can be found also more specific example script, e.g. to load Doppler or Polarization-Sensitive OCT data, in the same folder.

The MATLAB® version used for testing is MATLAB® 2017a.

4.1.4 Python

The Python SDK exposes the full functionality from the ANSI C SDK, including a collection of demo .py scripts to get the user started in developing customized software solutions.

- **Documentation and Introduction**
  C:\Program Files\Thorlabs\SpectralRadar\Manual\Python Reference\index.html
- **PySpectralradar-{VERSION}-py3-none-any.whl**
  C:\Program Files\Thorlabs\SpectralRadar\Python\PySpectralRadar\lib\
- **Demo Programs and .py Scripts**
  C:\Program Files\Thorlabs\SpectralRadar\Python\PySpectralRadar\Demos

Please see the section Installation Instructions for further information.

4.2 ThorImageAutomation (TIA)

ThorImageAutomation (TIA) is a light-weight API for performing OCT tasks through the ThorImage® OCT GUI. This is in contrast to the SpectralRadar API, which communicates directly with the device. SpectralRadar offers vastly greater flexibility, whereas TIA allows implementing simple OCT tasks with very little code.

- **Documentation**
  C:\Program Files\Thorlabs\SpectralRadar\Manual\ThorImageAutomation Reference.pdf
- **Location of the Header File ThorImageAutomation.h**
  C:\Program Files\Thorlabs\SpectralRadar\include\ThorImageAutomation.h and the ThorImageAutomation.lib at
  C:\Program Files\Thorlabs\SpectralRadar\lib\ThorImageAutomation.lib
- **C# ThorImageAutomationNET.dll**
  C:\Program Files\Thorlabs\SpectralRadar\DLL\ThorImageAutomationNET.dll
- **Python Files**
  C:\Program Files\Thorlabs\SpectralRadar\Python\ThorImageAutomation and its subfolders.
- **LabVIEW® Files and Subfolders**
  C:\Program Files\Thorlabs\SpectralRadar\LabVIEW
  This includes the ThorImageAutomation.llb and demo programs.

Chapter 5 Troubleshooting

Logging

The ThorImage®OCT keeps a log file of the operations performed by the software and the OCT device. This log file is located under:

C:\OCTData\ThorImageOCT_log.txt

To ensure that the log file does not grow excessively, the old log data is first moved to the folder listed below and then discarded:

ThorImageOCT_log.1.txt

Entries in the log file follow a standard format, containing a time stamp, the component from which the statement was logged and a severity of the log message. By default, ThorImage®OCT only logs high-priority messages. A log of all messages can be created by starting the ThorImage®OCT with the TRACE command-line option. This can also be achieved by starting the ThorImage®OCT (with diagnostic logging) through the start menu shortcut. Avoid starting the ThorImage®OCT with this shortcut when not diagnosing issues, as detailed logging may negatively impact performance.

Use of Log Files for Troubleshooting

Log files are a highly valuable tool for diagnosing issues. Log files will be most effective if the issue can be easily isolated. If the user is able to reproduce the issues consistently, please delete the existing log file from the aforementioned location, start the ThorImage®OCT with diagnostic logging and reproduce the issue. Then close ThorImage®OCT and copy the new log file to a secondary location, to ensure that no unrelated log messages are added to the file when running the ThorImage®OCT again. This archived log file may also be helpful for the OCT Technical Support.

Use the Troubleshooting Option in Settings

The Settings dialog offers several options for troubleshooting if the system is not running correctly. The options should in general be executed in the order of the setting dialog.

1. **Show Logfile:** Opens the ThorImage® OCT logfile. This logfile contains diagnostic- and error messages generated while ThorImage®OCT is running and may be helpful to diagnose error conditions.
2. **Restart Device:** Closes the device and re-initializes it, and all configurations will be reloaded.
3. **Reset Software Configuration:** Deletes the ThorImage® OCT settings file and restarts the ThorImage®OCT. This will reset all user settings to their default, but will not erase any OCT data.
4. **Reset Camera:** Resets all permanent settings of the camera, and re-initializes it to factory defaults.
5. **Reset Device Configuration:** Resets the device configuration to factory defaults (custom objective and probe calibration may be lost). This operation requires that the device is connected to the PC and switched on (otherwise the operation will show an error message).

Chapter 6 FAQs

6.1 OCT Engine

Starting the ThorImage®OCT fails with an error message stating "Unable to load DLL 'SpectralRadar.DLL".

The ThorImage®OCT uses a number of libraries installed in the DLL and plugins subfolders of the SpectralRadar installation. Third party applications may install conflicting versions of the same library, which keep ThorImage®OCT from starting correctly. Please use the ValidateLibraries tool shipped with the ThorImage®OCT to help diagnose these issues.

1. Using Explorer, open the SpectralRadar installation folder.
   Generally: *C:\Program Files\ThorLabs\SpectralRadar*
2. Open the subfolder "Service" and run the script *ValidateLibraries.cmd* by double-clicking the file.
   ➤ The script should now list one or more libraries that may interfere with the ThorImage® OCT
   Software libraries. For example, the output might look like this:

```
Thorlabs SpectralRadar Library Validator
========================================

Found SpectralRadar installation at 'C:\Program
Files\Thorlabs\SpectralRadar'.

Validating dependencies...

ERROR: Unexpected location for ZipWrapper.dll: Found at 'C:
\Programs\ThirdPartyApp\ZipWrapper.dll' instead of 'C:\Program
Files\Thorlabs\SpectralRadar\DLL\ZipWrapper.dll'.

Validation complete. Press any key to exit.
Press any key to continue . . .
```

This output would indicate that the program installed in *C:\Programs\ThirdPartyApp* is interfering with ThorImage®OCT. The concrete solution varies depending on the concrete program. Uninstalling the program if possible is the preferred solution. Re-installing the program after installing the ThorImage®OCT may also ensure that the ThorImage®OCT libraries can be loaded correctly.

The ValidateLibraries tool also generates a report in the file *SpectralRadar_Dependency_Report.txt*.

After starting the ThorImage®OCT, the following message appears in the toolbar: "The device could not be found. Please switch on the device.", although the OCT Imaging System is switched on. All operating modes except the data viewing mode are deactivated.

1. Close the ThorImage®OCT.
2. Switch the OCT engine off.
3. Check all connections between the PC and the OCT engine.
4. Check the probe cable and the fiber.
5. Make sure all cables are seated correctly.
6. Make sure the POWER and SYS OK indicators on the OCT engine light up when the device is switched on.
7. Switch the OCT engine on.
8. Start the ThorImage®OCT.

6.2 General Data Acquisition

When trying to acquire 2D images the OCT display remains dark. What are the possible causes for this?

1. Click the *Autoset Dynamic Range* button to adjust the dynamic range boundaries into an area where a signal is visible in the OCT display.
2. Verify that the distance between the probe lens and the sample is correct.
   Ensure the reference length adjustment is set correctly.
   ➤ Consult the SD-OCT hardware user guide for detailed instructions on adjusting the probe height and reference length.
3. Check if the optical fiber is correctly seated in the jacks on the probe and on the OCT device.
   ➤ Refer to the SD-OCT hardware user guide for further information.

User guides can be found here by typing the item #.

When using the SDK, the acquired data looks different from the acquired data with the ThorImage®OCT. What are the possible causes for this?

Please verify the following settings:

1. Probe Calibration File
   a. Use the SDK function "initCurrentProbe".
      ➤ If this does not work, try the following step.
   b. Check in the settings dialog in the tab "Hardware" which probe configuration file is selected.
      ➤ Make sure the same file is used during the call "intiProbe".
2. Speed/Sensitivity Settings
   ➤ Check whether the used speed/sensitivity settings is the same as the chosen preset in the SDK with function "setDevicePreset".
3. Scan Pattern Parameter
   ➤ The CenterX/Y, the angle of the scan pattern and specified sizes, e.g. SizeX or SizeY, should match the chosen numbers during creation of the scan pattern and modifying it with "rotateScanPattern" and/or "ShiftScanPattern".
4. Oversampling/Averaging
   ➤ Adjust the "setProbeParameterInt" and/or "setProcessingParameterInt". The applied A-Scan or B-Scan averaging need to match the oversampling and processing averaging parameters in the SDK.
5. Averaging Algorithm
   ➤ If A-Scan averaging is applied, the visual result depends on the used averaging algorithm. The averaging algorithm can be set using the "setProcessingAveragingAlgorithm" SDK function. By default, this is set to AScanAveraging_Mean. In contrast, the GUI uses AScanAveraging_Fourier_Max.
6. Processing Options
   ➤ Make sure that the chosen processing options in the ThorImage®OCT are applied with the different processing options in the SDK as well.

7. Image Field Calibration
   ➤ When image field correction is applied in ThorImage® OCT, it should also be implemented in custom user-coded programs using the ImageFieldCorrectionHandle.

The OCT image looks blurry. What are the possible causes for this?

1. Focus Plane of the Probe is Misaligned
   ➤ Refer to the OCT hardware user guide if in doubt.
2. Dispersion Between the Sample and Reference Arm
   ➤ Check whether the dispersion compensation is set correctly.
   ➤ Refer to the section Dispersion Compensation.

The software is not able to acquire very large acquisition sizes (taking into account pixel sizes in x and y as well as averaging parameters). What are the possible causes for this?

Increase the working memory (RAM) of the PC on which the ThorImage®OCT is running.
➤ Memory availability depends on a multitude of parameters which ThorImage®OCT cannot influence, due to general operating system principles. If problems are experienced acquiring the same large acquisition size several times, upgrading the RAM in the PC might resolve the problems.

When starting the ThorImage®OCT the error message "Non-paged memory size is 0. Please run ChangeMatroxSettings.cmd" appears. What are the possible causes for this?

The framegrabber inside the OCT imaging system's PC has a predefined memory configuration. This configuration has been set during production and needs to remain unchanged for the system to function correctly. Certain Windows® updates may reset this configuration.

1. Go to the installation folder of the ThorImage®OCT.
   Usually the following path: *C:\ProgramFiles\Thorlabs\SpectralRadar*
2. Search the folder "Service".
3. Save the entire work.
4. Run the script file "ChangeMatroxSettings.cmd" from the folder "Service".
   ➤ The script file "ChangeMatroxSettings.cmd" will automatically reboot the PC.
   ➤ The correct configuration is restored.

6.3 Anatomy of an OCT Scan

To understand the number of trigger signals required for a full OCT-Scan, it is very helpful to have a concept of the multiple sections making up an OCT-scan.
In general, an OCT-scan starts with the acquisition of a calibration spectrum called apodization. For this, the scan position is moved outside the field of view of the probe, so that no light from the sample returns to the sensor. Once the scanner has moved to this position, a calibration vector is captured and the scanner moves to the start of the actual scan region. The periods where the scanner is moving are called "flyback regions". Once the scanner is at the start of the scan position, it starts moving along the defined scan pattern and performs the actual OCT-scan.

The situation is slightly more complicated for volume scans. A volume is scanned as a series of linear B-Scans, one after the other, along the y-axis. To move from the end of one line to the beginning of the next, a "flyback region" is inserted between subsequent lines.

Additionally, there are two options for capturing the apodization vector in a volume scan: The apodization can either be performed between each of the B-Scans or alternatively once at the start of the volume, before the first B-Scan (the scan pattern using this type of apodization is called "fast volume scan pattern"). This behavior can be adjusted using the scan pattern creation.

The following chart illustrates the scanner movement for a single B-Scan (only one scanning axis is displayed):

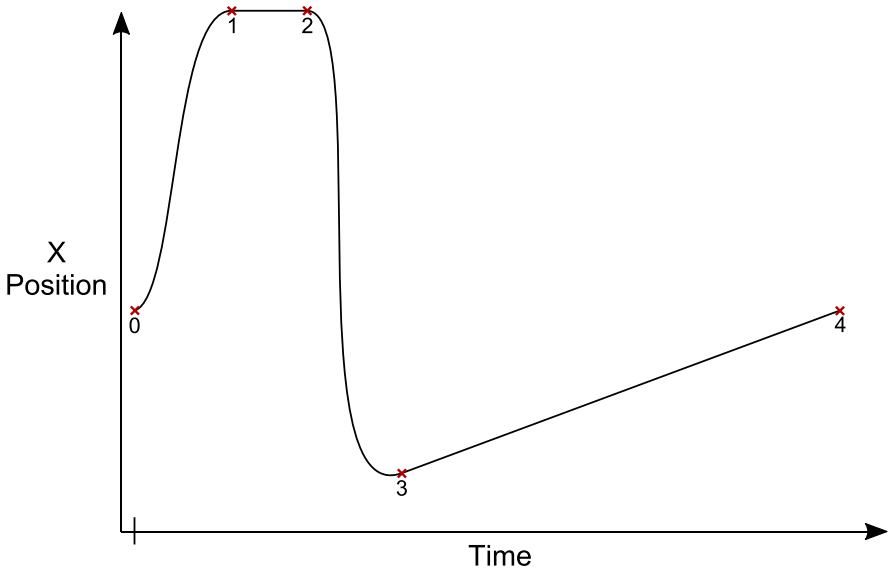


Figure 183 Chart of the Scanner Movement for a Single B-Scan

The indexed markings on the graph indicate the sections of the scan:

Index Marking	Description
0	Start of the scan, beginning of the flyback region leading to the apodization position (1). Please note that the scanning position at the start seamlessly connects to the end of the scan (4), this allows continuous looping of the scan pattern. The length of the flyback region (0 - 1 and 2 - 3) is a device-dependent constant in time, usually 2 ms. This means that the length of the flyback region expressed in number of A-Scans (see below) is dependent on the selected imaging speed of the device.
1	End of first "flyback region", start of the apodization region. The scanner has now reached a position outside the field of view of the probe and will remain stationary while the calibration spectrum is recorded. The duration of the apodization region (1 - 2) is a device-dependent constant in number of A-Scans, usually 25. If a fast volume pattern is used, the apodization region will be the same length as one imaging region (3 - 4).
2	End of apodization region, start of second flyback region. The scanner will now move to the start of the imaging region. The length of this region is identical to 0 - 1. Please note that the connection at point 3 matches the slope of the imaging region. This ensures that scanner will move across the imaging region at a constant velocity.
3	Start of the imaging region. The scanner moves along the configured imaging coordinates and the OCT data is captured. The length of this section (3 - 4) solely depends on the user-configured size of the scan.
4	End of the imaging region and scan. A continuous B-Scan would seamlessly loop back to 0 here, in a volume scan the next scan line would start.

Table 5 The Graph Indexed Markings Indicate the Scan Sections

6.4 External Triggering

Hardware Connection

The external trigger signal must be inserted by making an additional connection to the trigger channel through a tee connector. Please see the device-specific hardware user guide for details.

Trigger Signal Prerequisities

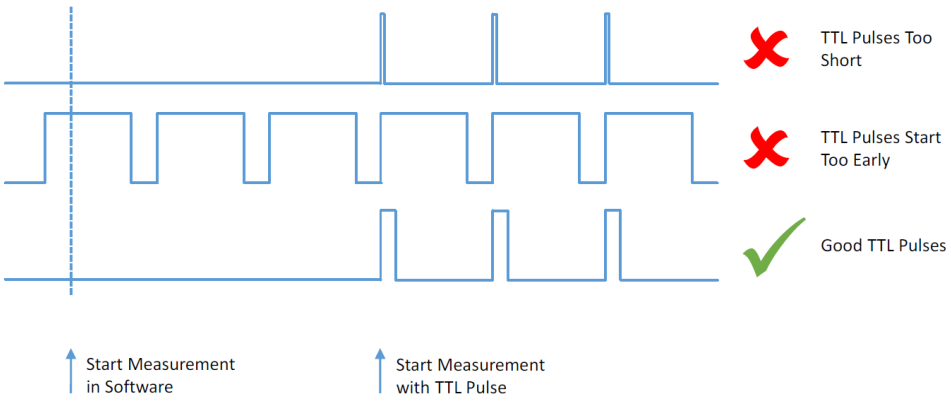


Figure 184 Illustration of Incorrect and Correct Trigger Signals

The measurement of each A-Scan starts at the rising edge of the signal. Trigger signal trains must be conditioned to fulfill the following criteria:

- The trigger signal is a typical TTL signal (low level below 0.8 V, high level above 2.0 V).
- The first trigger signal must be sent after the preparation of the measurement has been completed.
- The first trigger signal must be a complete and clear trigger signal (Do not disconnect and connect the trigger cable to simulate this).
- The trigger signal frequency must not exceed the maximum trigger frequency.
- The width of the low pulse should be at least 1 µs.
- The trigger is driven with the correct output impedance. Most devices use a 50 Ω termination resistor. Please see the device-specific hardware user guide for details.

Chapter 7 License Agreements

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